Wheat in Asia: Trends, Challenges and Research Priorities

3

R. Sendhil, Binita Kumari, Sayla Khandoker, Sahabuddin Jalali, Kamlesh Kumar Acharya, K. Gopalareddy, Gyanendra Pratap Singh, and Arun Kumar Joshi

Abstract

Wheat being a nutri-rich grain has a significant role in ensuring food and nutritional security for establishing zero hunger as committed under the Sustainable Development Goals (SDGs). The importance of wheat in Asia's food basket and nutrition is clearly depicted through a significant increase in area under the crop and a major quantum jump in its production in the past few decades. Nevertheless, the crop's increasing demand due to thriving population accompanied with production threats aggravated by climate change poses a serious challenge for the researchers and policy-makers. Asia is regarded as the major region having a tremendous potential to enhance the production and productivity of the wheat crop. There has been an increasing consumption

R. Sendhil (✉) · K. Gopalareddy · G. P. Singh
ICAR-Indian Institute of Wheat and Barley Research, Karnal (IIWBR), Karnal, India
e-mail: r.sendhil@icar.gov.in; Gopalareddy.K@icar.gov.in; director.iiwbr@icar.gov.in

B. Kumari
Rashtriya Kisan Post Graduate (RKPG) College, Shamli, India

S. Khandoker
Agricultural Economics Division, Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh

S. Jalali
National Statistics and Information Authority (NSIA), Kabul, Afghanistan
e-mail: S.jalali@nsia.gov.af

K. K. Acharya
ICAR-National Dairy Research Institute (NDRI), Karnal, India

A. K. Joshi
International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India
e-mail: a.k.joshi@cgiar.org

P. L. Kashyap et al. (eds.), *New Horizons in Wheat and Barley Research*,
https://doi.org/10.1007/978-981-16-4449-8_3

demand in Asia due to expansion in population and economic growth so much so that the importing countries in Asia have outnumbered the exporting countries. This calls for preparedness for a robust international trade. In order to acquaint with the existing scenario of wheat in Asia, trends in area, production, productivity and trade have been analysed in this chapter. The chapter also underlines the various constraints and challenges in Asian wheat production coupled with the priority area of research in order to improve the efficiency and sustainability across production systems.

Keywords

Wheat · Asia · Climate change · Biofortification · Sustainable agriculture · Precision agriculture

3.1 Introduction

Wheat (*Triticum species*) is one of the top two staple foods for millions and apparently the largest cultivated and traded cereal in the world (USDA 2020). Globally, the crop is being cultivated in around 220 mha with an annual output estimated at 769.31 million tonnes during 2020, of which Asia alone accounts for 36.25% (278.88 million tonnes) (USDA 2020). In Asia, much of the focus has been given on rice as the region produces almost 80% of the global output, but owing to the nutritional and calorie value of wheat, its role in food security and absence of a staple crop that can be grown during winter season, wheat has been able to accentuate its importance. Wheat provides around 20% of daily protein and food calories to 4.5 billion people, making it the second most important staple, after rice. Every 100 gm of wheat contains 72 g carbohydrates, 13.2 g proteins, 10.7 g fibres, 2.5 g fat and 0.4 g sugar along with 11% water and provides about 340 calories of energy. Nearly 55% of carbohydrates intake and 20% of food calories consumed in the world is attributed to wheat (Breiman and Graur 1995).

Asia represents the largest share (58%) of the culinary uses of wheat, followed by Europe (18%), but the per capita consumption is quite low, i.e., 63.62 kg per annum, compared to other continents of the world (FAO 2011). Among regions, Asia holds the maximum share in wheat area as well as production, but there has been a mixed trend in inter-regional trade. In the past decade, Southeast Asia and sub-Saharan Africa have emerged as the top importing regions, which previously were dominated by Middle East and North Africa (USDA 2020). In 2020, about 18% of the global import of wheat was contributed by Asia alone indicating the increasing demand put forth by the burgeoning population and changing food habits especially due to growing urbanization. However, in terms of productivity, it is far behind in comparison to several other regions of the world. However, there is a significant yield disparity within Asia as well. The concern is that the crop productivity has been declining in some countries, and the reduction could be as high as 25% per year (Rajaram 2012). On the other hand, the promising fact is that unlike some other crops, wheat production has witnessed rapid strides in the recent past and achieved record production in countries like India (Ramdas et al. 2012). Yet, there are multiple challenges including transboundary diseases.

By 2050, it is expected that the global wheat demand would increase by 60% over the current level (Rosegrant and Agcaoili 2010), largely due to Asia. Burgeoning population, abrupt variations in the climatic conditions as well as the declining farm size in a majority of Asian countries poses a serious concern on the sustainable production and trade. As there is no or limited scope for horizontal spread of the crop acreage, we have to rely on increasing the crop productivity using sustainable crop intensification practices as outlined under the Sustainable Development Goals (SDGs). Although wheat production and productivity have increased in some countries, yield plateau has been noticed in a majority of the countries that is largely due to factors such as low genetic enhancement, biotic and abiotic stresses, depleting natural resources, price volatility, climate change, etc. Among these, climate change is considered as the most serious issue as it is highly related to increasing temperature and reduced/erratic rainfall and hence has the potential to aggravate the negative impact on wheat productivity (Kumar et al. 2020). For instance, water deficiency alongside increased irrigation cost may lead South Asia to import about a quarter to one-third of its wheat by 2050 (Braun 2012).

Despite the growing economic importance of wheat in Asia, several issues need to be investigated for a timely addressal. Some of these issues are as follows: Will the current production trends with plateauing crop productivity able to meet the demand of the growing population? Are the buffer stocks sufficient to maintain the safety nets across Asian countries? What are the potential pathways and research strategies through which Asia can sustain its production in the context of SDGs? In addition, the present chapter analyses the trends in wheat production and trade, as well as efficiency gap among the Asian nations. Likewise, potential research and policy interventions have been suggested for increasing the efficiency of the regional production system. In this chapter we sourced secondary data on wheat production, area, yield, export, import and consumption for the period triennium ending (TE) 1970 to 2020 from multiple sources like the Food and Agriculture Organization (FAO) and US Department of Agriculture (USDA) to draw meaningful implications for sustainable production as well as regional trade.

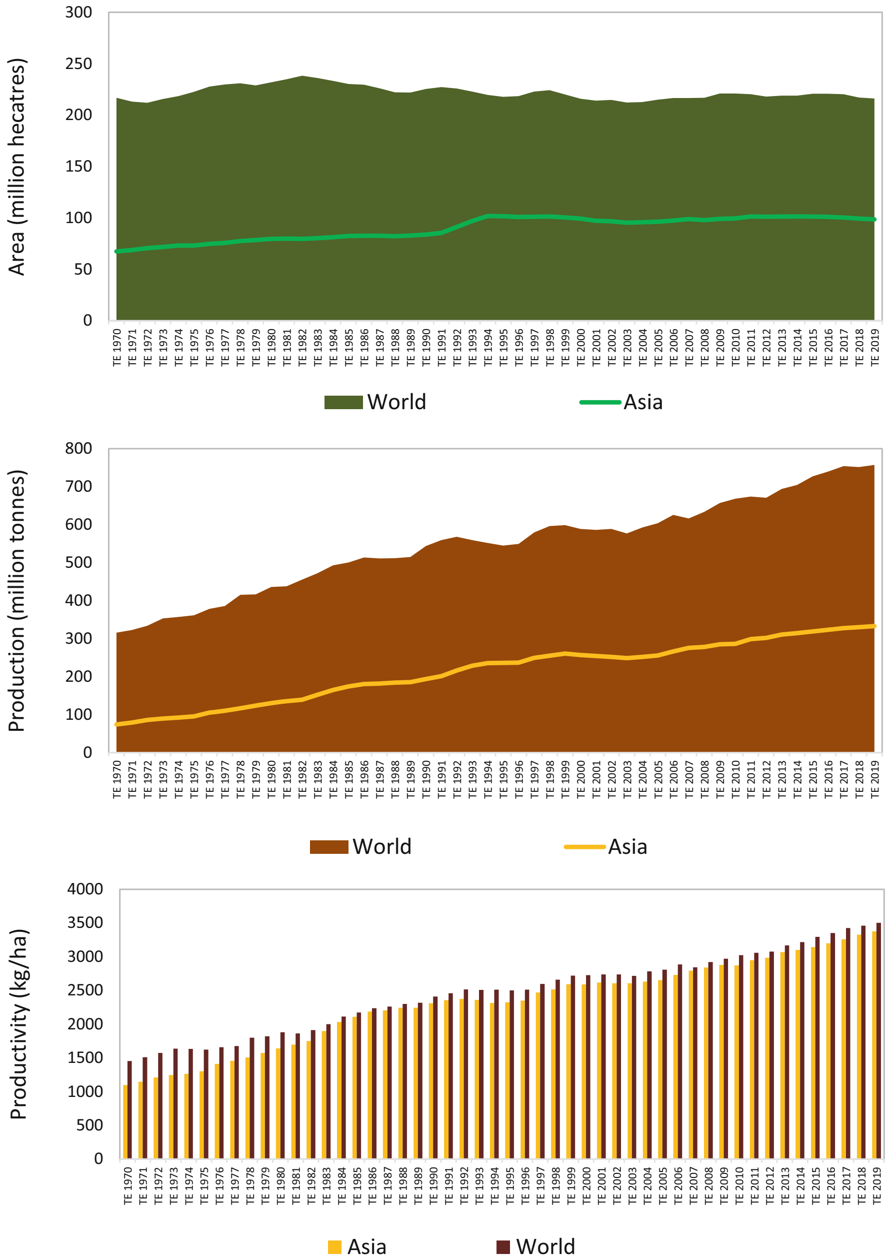
3.2 Trends in Area, Production and Productivity

Asia accounts for 46% of the global wheat acreage (TE 2019), the highest among all regions (FAOSTAT 2020). The production share is also highest (44%) (TE 2019) (Table 3.1) indicating its economic importance. The wheat area and production have increased, respectively, by 46% and 350% in a span of five decades (Fig. 3.1). Similarly, crop productivity has increased over years but less than the global average (Fig. 3.1). Among regions within Asia, South Asia registered the maximum growth in both area (65%) and production (361%) between TE 1970 and TE 2019 (Table 3.1). In terms of productivity, Asia has tripled its level over a period of five

Table 3.1 Area, production and productivity of wheat in Asia vis-à-vis other regions

Region	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2019
(A) Area (million hectares)						
Africa	9.05	8.31	8.26	8.91	9.38	10.04
Asia	67.35	79.58	83.68	99.21	99.56	98.58
• Central Asia	–	–	–	12.11	16.46	14.26
• East Asia	25.94	29.90	30.67	28.91	24.56	24.71
• South Asia	29.72	37.18	40.34	44.50	46.62	48.92
• Southeast Asia	0.07	0.09	0.12	0.09	0.10	0.06
• West Asia	11.62	12.41	12.55	13.59	11.82	10.63
Central America	0.87	0.73	1.02	0.72	0.77	0.60
North America	28.64	36.41	38.47	33.02	29.99	24.93
South America	7.91	9.33	9.51	8.15	8.34	9.07
Europe	94.00	86.41	75.30	53.87	59.56	61.63
Oceania	9.06	10.98	9.06	12.06	13.38	11.21
World	216.87	231.76	225.31	215.93	220.98	216.06
(B) Production (million tonnes)						
Africa	8.05	8.83	13.25	16.15	22.33	27.50
Asia	74.02	130.57	193.39	256.76	286.11	332.94
• Central Asia	–	–	–	15.06	22.68	21.82
• East Asia	29.22	58.17	93.25	108.64	115.47	134.42
• South Asia	32.08	52.26	74.52	105.34	119.63	148.04
• Southeast Asia	0.04	0.08	0.14	0.10	0.18	0.12
• West Asia	12.68	20.07	25.47	27.63	28.15	28.54
Central America	2.40	2.68	4.03	3.26	3.94	3.23
North America	54.46	76.28	83.95	90.04	89.10	81.96
South America	9.31	12.57	17.23	19.00	21.25	27.45
Europe	155.69	189.39	216.96	180.13	226.18	260.23
Oceania	11.48	15.35	14.58	23.31	19.34	23.84
World	315.41	435.68	543.40	588.65	668.25	757.15
(C) Productivity (kg/ha)						
Africa	891	1064	1610	1809	2373	2740
Asia	1099	1641	2310	2589	2873	3378
• Central Asia	–	–	–	1246	1373	1530
• East Asia	1126	1945	3038	3758	4702	5442
• South Asia	1079	1405	1847	2367	2565	3026
• Southeast Asia	533	879	1110	1063	1730	1863
• West Asia	1092	1618	2027	2033	2381	2684
Central America	2742	3664	3972	4561	5119	5402
North America	1918	2094	2162	2728	2972	3288
South America	1182	1350	1809	2328	2552	3025
Europe	1656	2188	2881	3344	3791	4221
Oceania	1259	1410	1609	1932	1436	2100
World	1455	1880	2409	2726	3023	3504

Source: FAOSTAT



Source: FAOSTAT

Fig. 3.1 Global trends in wheat area, production and productivity vis-à-vis Asia. Source: FAOSTAT

Table 3.2 Trends in wheat area for Asian countries (in '000 ha)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
Afghanistan	2094.0	2180.7	1600.0	2080.7	2356.0	2210.0
Bangladesh	105.0	295.6	583.2	839.7	386.3	347.1
Bhutan	6.1	8.2	6.4	10.2	2.9	2.1
China	25,072.5	29,232.1	29,794.0	28,427.8	24,055.4	23,999.6
Cyprus	67.8	12.4	5.3	6.2	6.2	8.5
India	15,860.6	22,089.5	23,557.9	27,235.1	28,082.8	29,817.7
Iran	5317.3	5582.5	6362.5	5339.8	6171.8	6700.0
Iraq	1400.0	1315.8	936.2	1300.0	1069.1	1180.4
Israel	107.4	90.1	90.3	71.1	64.9	58.0
Japan	279.4	150.7	275.4	171.3	208.0	211.9
Jordan	201.8	122.2	60.4	17.0	16.6	19.3
Lebanon	52.9	35.0	26.1	39.3	39.8	40.7
Mongolia	347.0	415.3	517.1	250.9	216.4	343.6
Myanmar	68.0	85.4	123.7	93.8	101.6	74.1
Nepal	208.6	363.4	600.1	649.4	710.9	706.8
North Korea	150.0	85.0	86.7	59.0	73.6	23.9
Oman	1.2	0.5	0.5	0.4	0.5	0.9
Pakistan	6124.0	6656.9	7627.5	8349.2	8909.1	8908.4
Saudi Arabia	70.7	66.4	759.1	428.6	247.2	89.8
South Korea	95.7	19.3	0.5	1.3	6.7	10.3
Syrian Arab Republic	1150.9	1483.2	1226.9	1667.7	1507.5	600.0
Turkey	8528.5	9210.7	9349.1	9246.6	7890.5	7179.5
Yemen	36.1	76.3	91.5	94.9	129.8	64.5

Source: FAOSTAT and USDA

decades but marginally less than the global average by 3.6% for TE 2019. Among Asian regions, East Asia exhibited the maximum progress (383%), followed by Southeast Asia (249%) and South Asia (181%).

An analysis of country-wise triennium ending (3-year average) figures on wheat acreage (Table 3.2) indicates that a majority of countries have shown a positive change, with India—the country with the largest wheat acreage in the world—showing an increase of around 14 million hectares (+88%). Next to India, Pakistan exhibited a notable change (2.78 million hectares, 45.47%), followed by Iran (1.38 million hectares, 26%). On the contrary, China—the largest wheat-producing country in the world—observed a negative growth in acreage in the recent three decades, post TE 1990. The transition of highest acreage from China to India happened during 2000 (FAOSTAT 2020). The area under wheat in China reduced by 5.79 million hectares (−19.45%), i.e., from 29.79 million hectares (TE 1990) to 23.99 million hectares (TE 2020). China has been followed by Turkey with an area reduction of 1.35 million hectares (−15.82%). In terms of percentage change, the highest positive growth was noticed for Nepal (+239%), followed by Bangladesh (+231%) and India

Table 3.3 Trends in wheat production for Asian countries (in '000 tonnes)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
Afghanistan	2296.3	2675.3	1783.3	2267.3	4073.0	4541.1
Bangladesh	85.7	554.9	986.7	1850.3	864.8	1183.1
Bhutan	6.2	8.2	4.4	14.8	5.1	4.1
China	27,985.3	57,262.6	91,491.6	107,747.4	114,255.3	133,679.1
Cyprus	63.5	15.6	10.5	11.8	12.0	18.1
India	18,428.3	33,029.0	50,043.0	71,333.8	80,017.7	103,610.0
Iran	4254.0	5845.0	7094.0	9572.0	10,412.0	16,016.7
Iraq	1318.7	856.7	872.1	771.3	1901.4	4270.5
Israel	151.9	184.5	234.6	92.7	107.0	72.2
Japan	747.8	496.9	985.7	613.6	708.9	911.6
Jordan	102.9	67.8	72.1	23.6	14.1	23.2
Lebanon	41.2	35.0	53.3	87.2	112.7	135.1
Mongolia	184.1	249.6	651.8	165.8	314.5	420.0
Myanmar	36.8	75.4	137.1	99.8	176.9	134.4
Nepal	234.1	422.2	809.9	1090.3	1490.8	1943.0
North Korea	87.7	108.3	124.3	104.0	168.0	35.0
Oman	1.9	0.3	0.9	1.1	1.7	3.6
Pakistan	6776.7	9724.6	13,803.3	19,210.1	22,767.5	25,158.7
Saudi Arabia	128.3	137.4	3433.4	1855.8	1495.8	586.4
South Korea	218.0	56.5	1.5	4.2	22.8	37.6
Syrian Arab Republic	742.7	1732.2	1719.0	3302.9	2974.7	1200.0
Turkey	10,092.3	16,962.3	18,922.0	20,000.0	19,352.0	19,333.3
Yemen	38.5	73.3	153.3	149.5	219.3	127.8

Source: FAOSTAT and USDA

(+88%). On the other hand, the highest negative growth was exhibited in the case of Jordan (−90%), followed by South Korea (−89%) and Cyprus (−87%).

Contrary to acreage, the production trend (Table 3.3) in wheat showed a positive progress in Asia barring a few countries like Bhutan, Cyprus, North Korea, Israel, Jordan and South Korea. The implication is that productivity has increased over years even for those countries which have shown positive production despite a negative growth in crop acreage. In fact, all countries registered a positive growth in national wheat productivity except Israel (Table 3.4). The top five producers of wheat in Asia are China, India, Pakistan, Turkey and Iran. In quantum terms, the change in production over five decades (Table 3.3) was highest in the case of China (+106 million tonnes, 378%), followed by India (+85 million tonnes, 462%) and Pakistan (+18 million tonnes, 271%). However, in percentage terms Bangladesh witnessed the maximum change (+1281%), followed by Nepal (+730%) and India (+462%). The analysis explicitly showcases the major quantum jump from the South Asian countries. On the contrary, decline in wheat production was significant in South Korea, followed by Israel and Jordan.

Table 3.4 Trends in wheat productivity for Asian countries (in Kg/ha)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
Afghanistan	1099	1228	1114	1084	1706	2178
Bangladesh	809	1869	1694	2205	2241	3410
Bhutan	1016	1000	682	1341	1789	1944
China	1116	1959	3068	3790	4750	5571
Cyprus	967	1266	1988	1910	1819	2128
India	1160	1495	2122	2618	2850	3474
Iran	800	1049	1115	1783	1662	2391
Iraq	939	651	914	581	1744	3618
Israel	1420	2024	2598	1243	1654	1249
Japan	2617	3319	3581	3575	3406	4302
Jordan	550	522	1194	1636	815	1198
Lebanon	789	1074	2040	2217	2820	3317
Mongolia	530	601	1264	675	1446	1223
Myanmar	533	879	1113	1068	1741	1812
Nepal	1120	1162	1349	1678	2096	2749
North Korea	585	1275	1441	1742	2284	1466
Oman	1583	485	1930	2919	3427	3853
Pakistan	1106	1457	1808	2299	2554	2824
Saudi Arabia	1817	2067	4523	4339	6039	6533
South Korea	2280	2865	3129	3233	3629	3656
Syrian Arab Republic	654	1170	1415	1972	1981	2000
Turkey	1183	1842	2022	2163	2451	2692
Yemen	1078	958	1680	1583	1686	1981

Source: FAOSTAT and USDA

Research progress for a specific agricultural commodity is generally captured by the trend in the potential yield of crop varieties which is a proxy variable on the outcome of research innovations and interventions. To compare the research progress between countries, crop productivity is considered a better metric although it depends on regional factors like agro-climatic conditions, investment on R&D, etc. The top five countries that registered higher productivity for the TE2020 are Saudi Arabia (6533 kg/ha), followed by China (5571 kg/ha), Japan (4302 kg/ha), Oman (3853 kg/ha) and South Korea (3656 kg/ha) (Table 3.4). Yield levels in Saudi Arabia are significantly high due the to the government's decision on supplemental irrigation, in 2019, after rescinding partially from the virtual ban on wheat production that was in place for about 3 years.[1] It is explicit that barring Israel, all countries in Asia registered a commendable progress over a period of five decades. The change was more prominent in the case of Saudi Arabia (+4716 kg/ha, 260%), followed by China (+4455 kg/ha, 399%) and Iraq (+2679 kg/ha, 285%). In terms of percentage, the maximum progress was witnessed for China (+399%), followed by Bangladesh

[1] https://www.world-grain.com/articles/11796-saudi-arabia-grows-wheat-production

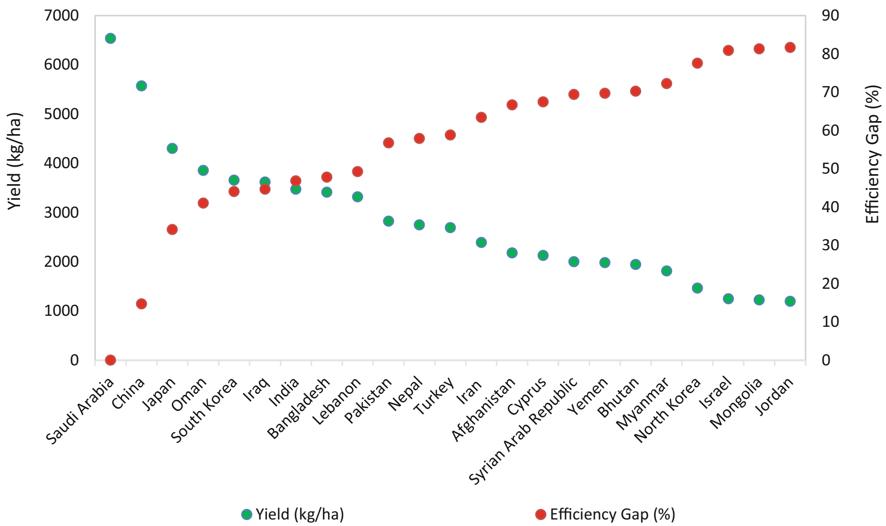


Fig. 3.2 Yield levels (kg/ha) vis-à-vis efficiency gap (%)

(+321%) and Lebanon (+320%). Hence, among the Asian regions, South Asia progress has been remarkable in terms of crop productivity.

Alternatively, productivity difference between countries reflects the efficiency range of the region in producing the maximum possible output in a given piece of land. Hence, efficiency gap[2] was estimated and plotted for selected Asian countries to know the level of existing gap among countries (Fig. 3.2). The benchmark country in wheat productivity is Saudi Arabia since it registered around 6533 kg/ha for the TE 2020, the highest among all. The figure shows a range of efficiency gap within Asian countries implying the scope of increasing the crop productivity with suitable research interventions and innovations. The gap is highest in the case of Jordan (82%) and least for China (15%). Though crop productivity (as measured by kg/ha) is a better metric to judge the relative progress between countries, a better estimate for comparison would be the per-day productivity as duration and type of wheat (spring or winter) influence productivity, barring external factors which are beyond the control. Winter wheat is generally highly productive with a long (about 10 months) duration, whereas the spring wheat is less productive with much shorter (about 4–5 months) duration. Hence, to count the trade-off and have a relevant

[2]Efficiency gap (EG) is a ratio measure for analysing the difference in the crop productivity between countries by comparing the productivity of a country to the benchmark (highest productivity) country. It is calculated using the following formula, and the metric varies from 0 to 100%:

$$\text{Efficiency gap} = \left[1 - \left(\frac{\text{Actual yield}}{\text{Benchmark yield}}\right)\right] \times 100$$

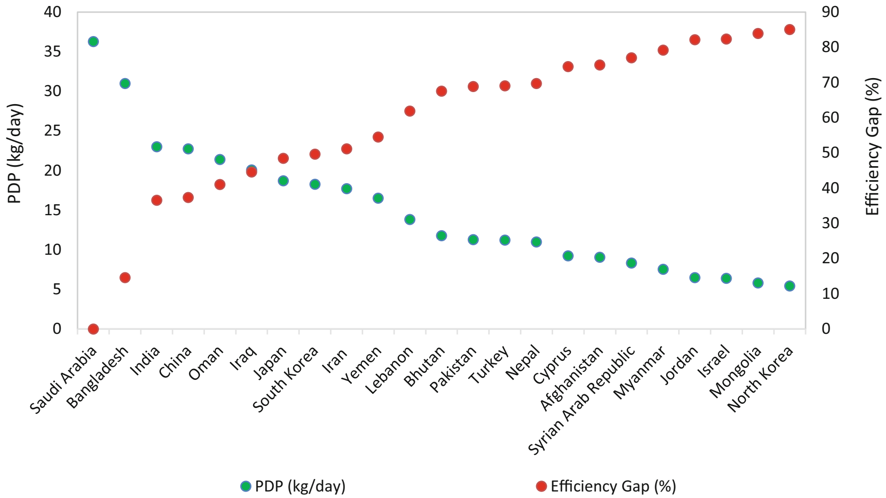


Fig. 3.3 Per-day productivity (kg/day) vis-à-vis efficiency gap (%)

comparison metric, per-day productivity is suggested. Accordingly, a comparison has been made among the selected wheat-producing Asian countries (Fig. 3.3).

It is explicit from Fig. 3.3 that the ranking of several countries changed relative to the earlier comparison made by ignoring the duration of the wheat crop. For instance, India is relatively in a better position in comparison to China owing to the difference in the type of wheat under cultivation. In India spring wheat is grown with an average duration of 5 months (around 150 days) though the duration differs across agro-climatic conditions. On the contrary, winter wheat is widely cultivated in China which has the duration of about 230–260 days. In absolute terms, the estimated productivity for the TE 2020 is 5571 kg/ha for China and 3474 kg/ha for India (Table 3.4). On the contrary, the per-day wheat productivity for China and India is estimated at 22.7 kg and 23.0 kg, respectively. The implication is that the productivity in China despite being higher than India on absolute terms notices a reversal pattern if per-day productivity is considered. A similar pattern is noticed if India and Bangladesh are compared. In this pair, the type of wheat cultivated in these countries is not a concern as both the countries grow spring wheat, but the duration of the crop makes a count. The duration of wheat grown in Bangladesh is less than the Indian wheat by around 30 days and hence the difference.

3.3 Trends in Trade

This section deals with the wheat trade in Asian countries with the rest of the world. Despite Asia having a high share in global wheat production, consumption has been increasing over years leading to large-scale import from countries of other regions. On the other hand, surplus production in countries like India and Turkey lets these

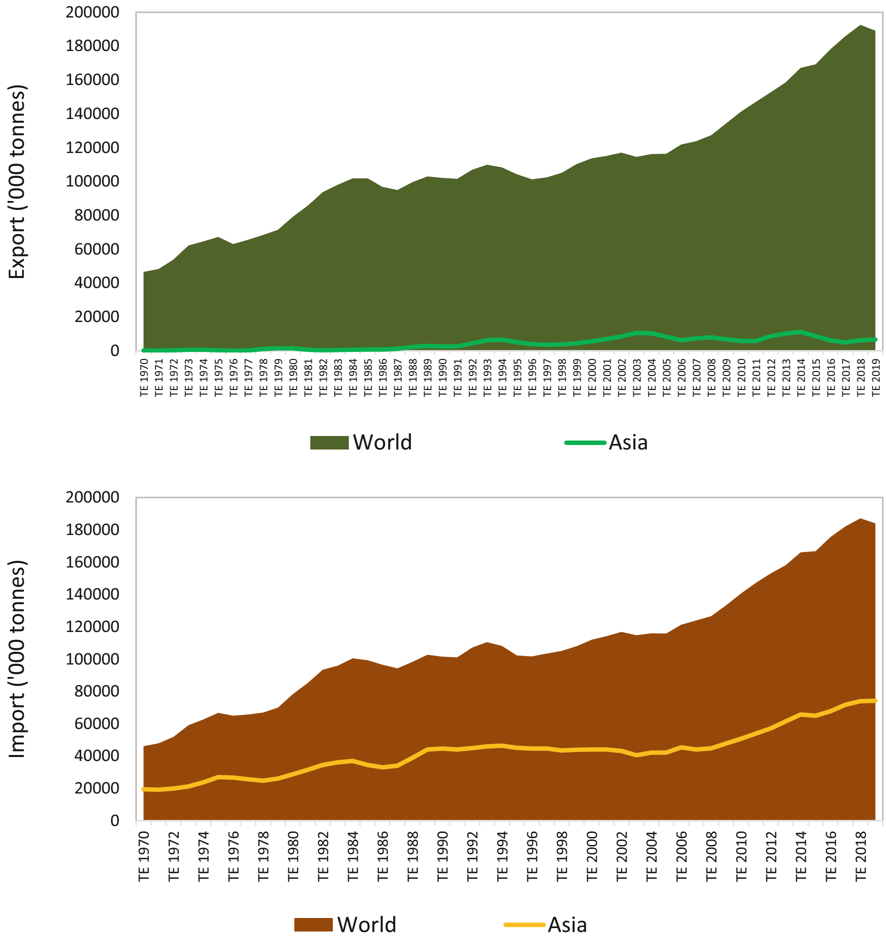


Fig. 3.4 Global trends in wheat exports and imports vis-à-vis Asia

nations export which could be within Asia as well. In general, for Asia, the imports are more than its exports (Fig. 3.4 and Table 3.5). This matches with the fact that the number of importing countries in Asia is much higher compared to those who export (Tables 3.6 and 3.7). This not only indicates an increasing demand to meet consumption but also about the existence of immense scope for processing industries. In the past 5 years, Asia accounted for only 3.5% of the global wheat exports, while import was about 40%.

In the two economic variables, i.e., exports and imports, there existed a mixed pattern (year to year) among the Asian countries but as a whole region registered an increase over years. Unlike rice—a robust crop—which can be cultivated in any environment, wheat is adaptable only to certain agro-climatic conditions. Hence, the countries that don't cultivate wheat have to import for meeting their domestic

Table 3.5 Exports and imports of wheat in Asia vis-à-vis other regions

Region	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2019
(A) Export (‘000 tonnes)						
Africa	52.25	137.08	585.31	187.08	144.83	126.83
Asia	186.44	1435.44	2644.58	5661.96	5799.80	6612.95
• Central Asia	–	–	–	3523.21	4487.75	5458.70
• East Asia	6.43	1.66	29.90	3.97	44.86	8.67
• South Asia	142.73	422.81	56.49	282.74	306.83	884.72
• Southeast Asia	15.82	16.72	43.70	5.04	33.21	43.95
• West Asia	21.45	994.24	2514.49	1847.00	927.15	216.91
Caribbean	–	–	2.05	8.41	1.55	0.52
Central America	99.08	17.64	134.08	338.70	992.49	690.32
North America	24,114.59	48,792.29	51,313.85	45,303.68	44,373.30	48,106.71
South America	2381.91	3460.67	4791.01	10,213.94	8576.93	12,823.05
Europe	13,667.72	14,567.11	31,317.77	35,499.16	68,344.59	106,085.61
Oceania	6124.09	10,883.08	11,381.34	16,498.93	13,058.64	14,645.19
World	46,626.07	79,293.31	102,170.00	113,711.86	141,292.13	189,091.18
(B) Import (‘000 tonnes)						
Africa	3319.24	10,556.35	14,728.04	20,970.35	35,686.14	45,338.06
Asia	19,439.81	28,684.46	44,617.02	44,095.68	50,750.29	74,194.87
• Central Asia	–	–	–	1005.68	2118.33	3555.21
• East Asia	10,957.04	17,852.60	23,990.80	12,416.45	10,989.72	14,620.44
• South Asia	5509.37	3983.22	8662.48	11,647.28	9142.63	9249.37
• Southeast Asia	1193.62	3171.92	4291.58	7801.51	10,826.45	25,494.30
• West Asia	1779.78	3676.72	7672.16	11,224.77	17,673.16	21,275.55
Caribbean	555.46	1241.19	1740.85	1628.20	1694.13	1836.59
Central America	308.65	1301.17	1304.31	3786.70	4532.37	6598.11

North America	31.40	3.83	479.35	2076.96	2606.85	2720.00
South America	4518.13	7800.97	4531.26	11,824.97	11,721.08	13,826.99
Europe	17,937.35	28,721.39	33,886.55	27,169.30	32,940.02	38,396.06
Oceania	24.90	102.41	288.14	436.04	576.08	1103.52
World	46,134.94	78,411.76	101,575.52	111,988.20	140,506.95	184,014.21

Source: FAOSTAT

Table 3.6 Trends in wheat imports for Asian countries (in '000 tonnes)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
Afghanistan	59.3	67.9	205.0	339.3	513.2	2230.8
Bahrain	0.4	29.8	27.9	58.5	72.5	132.7
Bangladesh	894.2	1327.6	1878.3	1688.0	2318.1	6046.4
Bhutan	21.2	0.8	8.4	10.9	3.1	2.0
China	4497.9	9116.3	13,984.8	937.8	714.8	4458.7
Cyprus	29.0	48.9	75.9	86.3	105.9	101.3
India	3762.5	314.5	629.2	1058.6	116.6	43.4
Indonesia	5.3	1015.5	1706.3	3245.5	4654.3	10,565.4
Iran	185.9	820.2	3624.7	5423.0	3533.1	677.7
Iraq	98.8	1687.0	2666.7	2450.6	2622.8	2423.5
Israel	360.7	489.5	604.1	1543.1	1728.1	1722.0
Japan	4361.7	5724.1	5592.1	5861.7	5319.6	5617.4
Jordan	21.6	179.2	394.4	611.6	796.5	1007.9
Kuwait	72.2	148.8	138.7	227.5	321.7	486.9
Lebanon	291.4	309.3	239.0	404.1	487.6	992.1
Malaysia	323.8	470.4	749.7	1169.7	1032.8	1670.6
Nepal	0.0	18.9	23.1	11.0	0.8	149.2
North Korea	229.7	443.3	440.0	424.2	96.2	343.3
Oman	0.3	43.8	122.1	250.5	223.1	723.6
Pakistan	562.0	1296.8	1606.4	2269.3	1672.3	0.0
Philippines	511.9	721.8	1267.3	2181.7	2214.2	6963.6
Qatar	1.8	40.9	45.9	46.3	119.4	250.9
Saudi Arabia	77.5	172.6	135.2	16.1	1056.6	2501.2
Singapore	266.8	314.9	261.4	127.0	180.8	370.3
South Korea	1111.5	1733.9	2969.1	4071.0	3623.9	3788.0
Sri Lanka	24.2	136.7	687.4	847.1	985.4	1009.9
Syrian Arab Republic	250.6	60.8	848.7	5.8	989.2	483.4
Thailand	51.3	152.8	272.7	681.0	1166.4	3149.0
Turkey	510.1	0.0	1409.1	1432.5	3218.1	7760.6
United Arab Emirates	0.7	75.8	222.4	1012.1	1173.9	1579.2
Vietnam	34.4	486.1	34.2	364.4	1435.5	3751.1
Yemen	64.8	390.4	741.9	1375.9	2560.6	3547.4

Source: FAOSTAT and USDA

requirement emerging from households' consumption and/or agro-processing industries.

Barring a few countries like Bhutan, India and Pakistan, the rest have shown a considerable increase in the quantum of imports, although a mixed pattern was observed in the past five decades. Indonesia is the largest importer of wheat in Asia, followed by Turkey, the Philippines and Bangladesh. Further, a majority of the Middle East countries import wheat. Interestingly, a handful of countries are engaged in both import and export. For instance, Indian wheat exports surpass imports, and hence the country emerged as a net exporter since 1978 (Chand

Table 3.7 Trends in wheat exports for Asian countries (in '000 tonnes)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
China	0.0	0.0	3.7	3.2	44.8	669.1
Cyprus	8.7	0.0	0.0	0.0	0.0	0.0
India	0.1	422.8	55.7	271.8	0.5	556.1
Jordan	0.8	0.6	1.7	0.0	2.0	41.1
Lebanon	1.1	2.7	0.0	0.0	25.6	1.9
Malaysia	0.1	0.0	1.8	3.3	3.2	122.1
Mongolia	2.2	1.6	26.1	0.0	0.0	1.7
Nepal	0.5	0.0	0.1	0.4	15.2	6.7
Oman	0.0	1.9	6.7	26.6	6.7	7.5
Pakistan	71.8	0.0	0.7	10.4	59.0	783.6
Saudi Arabia	0.0	0.0	1642.4	0.0	0.8	41.7
Singapore	15.7	16.6	41.9	0.9	0.1	80.6
Syrian Arab Republic	1.8	7.0	9.4	180.1	65.2	0.0
Turkey	0.5	981.8	852.6	1585.4	494.5	4423.3
United Arab Emirates	0.0	0.2	1.6	36.6	305.0	97.4
Yemen	3.4	0.0	0.0	0.1	0.7	0.2

Source: FAOSTAT and USDA

2001). Among the probable reasons, imports arise either for cheap priced grain at international markets or requirement as seed material.

Like wheat imports, exports have exhibited a mixed trend for over five decades. China, India, Pakistan and Turkey have shown a considerable increase in the quantum of exports over years. Among the selected countries, Turkey holds the top position in wheat exports, followed by Pakistan and China. Of them, Turkey and China are net importers in recent years such that the quantum of imports exceeded exports for the TE 2020.

3.4 Trends in Consumption

Globally, wheat is a staple food for about 2.5 billion people and provides about 20% calorie intake to an average person. However, in West and Central Asia, it provides around >50% of calorie requirement (Ramadas et al. 2019). Hence, it is one of the cheapest sources of calorie, protein and a number of micronutrients. The consumption trend of wheat has shown a radical shift since TE 1970 to TE 2020 (Table 3.8). Almost all Asian countries have shown an increased level of consumption of wheat, with China on the top, followed by India and Pakistan (Table 3.8). In terms of percentage change, Bangladesh displayed the maximum, followed by Thailand and Myanmar. Clearly, the South Asian countries have witnessed the increased demand for wheat driven by population and changing consumers' preference.

Table 3.8 Trends in wheat consumption for Asian countries (in '000 tonnes)

Country	TE 1970	TE 1980	TE 1990	TE 2000	TE 2010	TE 2020
Afghanistan	2398	3011	1788	2589	6093	7700
Bangladesh	99	2433	2580	3372	3700	7358
Bhutan	–	6	4	20	27	22
China	32,081	65,160	102,264	109,289	108,333	127,000
India	21,009	34,679	49,908	66,610	76,946	97,080
Iran	3961	7167	11,167	14,867	15,400	16,533
Iraq	1413	2502	3433	3573	5822	7533
Israel	474	734	928	1550	1817	1900
Japan	5206	6084	5903	6167	6197	6327
Jordan	272	389	550	768	839	907
Kuwait	72	249	143	213	343	536
Lebanon	392	387	188	475	579	1450
Mongolia	233	360	638	314	546	469
Myanmar	54	99	135	186	332	642
Nepal	231	460	807	1137	1547	2105
North Korea	393	356	439	612	633	465
Pakistan	7651	10,669	15,469	20,745	22,933	25,400
Saudi Arabia	403	820	1483	1883	2850	3460
South Korea	1493	1895	2933	3681	3926	3517
Syrian Arab Republic	1095	2154	2851	3285	4683	4167
Thailand	64	182	342	743	1257	2800
Turkey	9155	12,302	14,277	16,688	17,100	19,500

Source: FAOSTAT and USDA

3.5 Production Constraints and Challenges Ahead

- **Population vis-à-vis growing demand:** About 60% of the world's population resides in Asia with China and India alone accounting for 40%. As already discussed earlier in the chapter, China, India, Pakistan, Turkey and Iran are the top most producers of wheat. The annual growth rate of wheat productivity in these countries is at par with that of production. Hence, if the production and productivity of wheat continue to be favourable, Asia would be able to meet not only the regional demand but the global demand as well. All the major wheat-producing Asian countries that were involved in Green Revolution are self-sufficient today, except Afghanistan, Bangladesh, Iraq and Yemen (Braun 2012). For instance, in Bangladesh, keeping in mind the highest percentage change in consumption (Table 3.8) due to the increasing population along with the embedded crop production constraints, limited natural resource availability, changing agro-ecological conditions and government policies related to agriculture, renewed research thrust has to be given to generate technologies to meet the wheat demand.

- **Climate change:** Climate variability explains almost 60% of yield variability and is a crucial factor influencing food production and farmers' income (Maitu et al. 2017). The two major abiotic stresses of wheat aggravated by climate change are heat and drought (Joshi et al. 2007a). It has been reported that these two stresses will intensify in the future and may have a significant impact for wheat in India and South Asia (Joshi et al. 2007b). In fact, most of the rice-wheat area of South Asia, with mean daily temperatures above 17.5 °C in the coolest month, is already heat stressed (Fischer and Byerlee 1991). It is well known that wheat is highly sensitive to both high night and day temperatures (Wheat Initiative 2019). In India, it is predicted that with every 1 °C rise in temperature, the wheat output is expected to decline by 4–6 million tonnes (Aggarwal 2009). Concerns have been raised that in the vast Indo-Gangetic plains, the major food basket of South Asia may become inappropriate for wheat production by 2050 as per the projections due to heat stress (Ortiz et al. 2008). Crop yield studies suggest that global warming has reduced wheat yield by about 5% (Aryal et al. 2019). Negative trends in solar radiation and an increase in minimum temperature have resulted in declining trends of potential yields of wheat in Indo-Gangetic plains of India (Pathak et al. 2003). Another issue is shortage of water, which is a major limiting factor in South Asian countries and China. In the 20 mha wheat belt of water-rich Indo-Gangetic plains, water may soon become a limiting factor for sustained production (Joshi et al. 2007b). Likewise, water is a limiting factor for wheat production in China, specifically in the northern part of Yellow and Huai valley. Also, global warming has advanced the heading date by 7–10 days in northern China, but maturity period remains basically unchanged. Clearly, the adverse impact of climate change is evident in a majority of the Asian countries which needs due attention and adaptation strategies.
- **Irrational use of inputs and resources:** Wheat is a crop to which the most nitrogen fertilizer is applied globally. Of the total fertilizers applied globally, 70% is applied in the developing world, most of it only in three countries: China, India and Pakistan. The major cropping system prevailing in South Asia right from northern Pakistan to Northwest Bangladesh via Indo-Gangetic plain is rice-wheat cropping system which is highly intensive for labour, water and capital. A continuous adoption of rice-wheat cropping in South Asia since Green Revolution has led to decline in productivity and hence questions have been raised about its sustainability (Hobbs and Morris 1996; Joshi et al. 2007a).

  In order to improve profits, production and sustainability of this sequence scientists recommended different resource conserving technologies (RCTs) like zero tillage, laser levelling, irrigation-based soil matrix potential, bed planting, direct seeding, mechanical transplanting of rice and crop diversification for this purpose (Bhatt et al. 2016). In India, RCTs like zero tillage, rotary till and rotavator were popularized among the wheat cultivators in early 2000s (Sendhil et al. 2019). Side-by-side issues and breeding targets were defined for researchers who seek to improve crops for reduced tillage systems (Joshi et al. 2007a). A major amount of wheat produced in Asia is a result of over-extraction of groundwater for irrigation. Faulty irrigation practices result in enormous losses in water for irrigation. For instance, in most countries of South Asia, wheat is planted on flat basin that is directly flooded for irrigation. Shortage of groundwater in such countries has led to the limited use of tube wells, and this shortage is expected to worsen over the next coming decades. With the use of optimum agronomic practices, stress-tolerant wheat varieties and the efficient irrigation technology like drip irrigation, the water consumption of the crop can be reduced by 30–50%. In this context, irrigation has been reduced from 4–5 times to 2–3 times in China, during wheat season with water-saving technologies such as bed planting. Likewise, a number of wheat varieties have been released in India that perform well under for limited (one or two) irrigation.

- **Emerging pests and diseases:** Wheat crop is attached by a number of insects' pest and diseases, most of them being transboundary in nature. New breeds of insects and pests which are resistant to insecticides have also emerged over the past few decades. Wheat rust diseases are the most important diseases of wheat occurring in almost all wheat-growing countries. Host resistance serves as the cheapest, effective and most environment-friendly method to combat the three rust diseases of the crop. From the last few decades, there has been no record of serious rust epidemic in India due to deliberate diversification of the host resistance genes in the wheat varieties. Among all the three rusts, stripe rust is the most devastative one in counties like India, Pakistan, Afghanistan and Iran. In Central Asia too, stripe rust is the most devastating disease, and more than five epidemics have occurred in the last two decades. In the end of the last century, wheat was seriously threatened by the Ug99 race of stem rust, caused by *Puccinia graminis f.* sp. *tritici*. The virulent race of Ug99 was first identified in Uganda in 1999 and started spreading to other countries of Africa with a high potential to reach Asia (Singh et al. 2008; IAEA 2009). To manage this, the Borlaug Global Rust Initiative (BGRI) was initiated in 2008, jointly by CIMMYT, ICARDA, FAO, ICAR and Cornell University, which made a significant progress by releasing a large number of resistant wheat varieties in countries like India, Nepal, Bangladesh, Pakistan, Afghanistan and Africa, along with a fast-track seed dissemination through a project funded by the USAID (Joshi et al. 2011). Recently, wheat blast that emerged in Bangladesh in 2016 is a serious cause of concern for many countries of Asia (Malaker et al. 2016; Chowdhury et al. 2017).
- **Deteriorating soil quality:** Soil health is deteriorating at an alarming rate with reducing micro- and macro-soil nutrients (Fujisaka et al. 1994). Owing to reduced soil nutrient status due to overuse of rice-wheat cropping system and imbalanced nutrient application, farmers have to use more doses of fertilizers to get higher yields, which not only lead to increased cost of cultivation but also further deteriorate soil quality in the long run. In India about 4.5 million hectares of saline soil is under wheat cultivation, and despite the availability of soil reclamation measures, the pace of reclamation is not substantial. Hence, there is a significant impact of soil salinity on wheat yield in those areas. Sequestration of soil organic carbon (SOC) is one of the important strategies not only to improve soil quality but also to mitigate climate change. Better soil management increases water use efficiency and maintains soil quality that eventually adds to sustainable

agriculture. Further, nitrogen use efficiency (NUE) of the crop in developing countries is around 33% but can be increased to 65% if weather-related information is available to the farmers as NUE is linked to rainfall.

- **Farm holdings vis-à-vis technical efficiency:** Cereal-legume intercropping systems have the potential to increase yield, land use efficiency as well as efficiency in the utilization of natural resources such as water, light and nutrients. Availability of improved varieties along with the use of irrigation and fertilizer in rice-wheat farming system has shown remarkable increase in overall production. But recently the system has been reported to have shown stagnant yields and the factor productivity, which poses a serious concern and hence is subject of on-going research programme by national and international institutions. However, in many countries farm size is quite small including Eastern Gangetic Plains of India, Bangladesh and China. In fact, one of the major production constraints of wheat in China is small farm size (0.65 ha[3]) which hinders the technical efficiency of the farms.
- **Human nutrition:** Wheat plays an important role to ensure both food and nutritional security in most of the countries of Asia. This is not only true for South Asia but also for Central Asia which comprises Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. In these Central Asian countries, wheat is the most important food crop, and the daily per capita calorie drawn from wheat in this region is the second highest in the world after Middle East and North Africa. In case of Kyrgyzstan and Tajikistan, even though their National Food Security Programs aim to achieve wheat self-sufficiency, these countries apply more liberal agricultural policy measures and remain heavily dependent on wheat imports (Svanidze et al. 2019). In Bangladesh, the demand for wheat will increase in the future due to changing food habits, raising farm income and meeting nutritional requirement (Timsina et al. 2018). In Nepal, wheat is the third important crop after rice and maize in terms of production and area but ranks second in terms of food security. People who depend on cereal-based diet or reside in region where soils are deficit in minerals often suffer from malnutrition. It has been observed that a major issue is deficiency of zinc. Hence, biofortification approach is being employed in wheat to address this issue of malnutrition. In the last few years, varieties rich in grain Zn have been released in India and Bangladesh. In the last year 2020, five Zn-rich wheat varieties were released, and their fast-track seed dissemination is underway.[4]
- **Price volatility:** Many factors affecting wheat prices include climate, yields, oil prices, lagged prices and imports. Increasing wheat consumption demand, alongside increasing population, poses threat on wheat prices causing it to rise. On the supply side, climate and oil prices are the two important factors affecting wheat production and ultimately their prices. Oil prices affect wheat prices directly

[3] https://www.adama.com/en/our-commitment/global-farming/farming-stories/insight-into-agriculture-in-china

[4] https://www.cimmyt.org/news/historic-release-of-six-improved-wheat-varieties-in-nepal

through production inputs and indirectly through demand for biofuels and resulting substitution effects (Enghiad et al. 2017). A high level of trade fosters market integration and contributes to stabilization of prices. In Central Asia, an improvement in the storage capacity would facilitate managing the wheat price risk and contribute to stabilizing whet prices and reducing price volatility (Svanidze et al. 2019).

- **Declining R&D investment:** The priority areas of research and development are to break the yield barriers and increase wheat productivity under looming challenges. This include investments in modern breeding tools like modern genomics, speed breeding, pre-breeding, improved input (water, nitrogen and radiation) use efficiency and platforms to develop biotic (heat and drought) and abiotic (disease and pest) stress-tolerant cultivars. In India, the future of wheat production depends heavily on the application of these modern technologies in improving various disciplines of wheat research such as breeding, integrated pest management, water management, nutrient management and even genetically modified wheat. Investments must be made to accelerate the genetic gains through broadening of genetic base, development of precision phenotyping facilities, high-throughput phenotyping platforms (HTPPs) and high-throughput genotyping platforms (HTGPs) and should aim at unlocking the natural variation available in the gene bank via novel genomic tools like genomic selection. Developed countries like the USA and Japan spend about 6.9% and 14.5% of their agriculture GDP on agriculture R&D, respectively, whereas India spends only about 0.5% of agriculture GDP on agriculture R&D which is growing at about 2% per annum (Nayak and Huchaiah 2019). Further investment in R&D by both public and private sectors will boost the productivity and profitability of farmers, as this investment would ultimately lead to sustainable productivity enhancement.

3.6 Bibliometric Analysis

In this section, bibliometric analysis on wheat research in Asian countries is highlighted to capture the research trends. Data required for the analysis has been retrieved from Scopus database. Scopus provides an easy access to the data required for bibliometric analysis, and the retrieved data was used for mapping with the help of VOSviewer software. To have a clarity that a particular document represents only wheat-based research, we considered only those documents in which the article title carried the word ‘wheat’. We restricted our study only to the past 20 years of research conducted in Asian countries in the field of wheat that were published in an open-access journal. The steps used in retrieving the relevant documents are presented in Fig. 3.5. A total of 1955 documents from the Scopus database were retrieved finally. The bibliometric analysis showed that wheat research was dominating in the field of agricultural and biological sciences. Perusal of Fig. 3.6 indicates that almost half of the research papers were contributed by agricultural and biological sciences followed by environmental sciences, biochemistry, genetics,

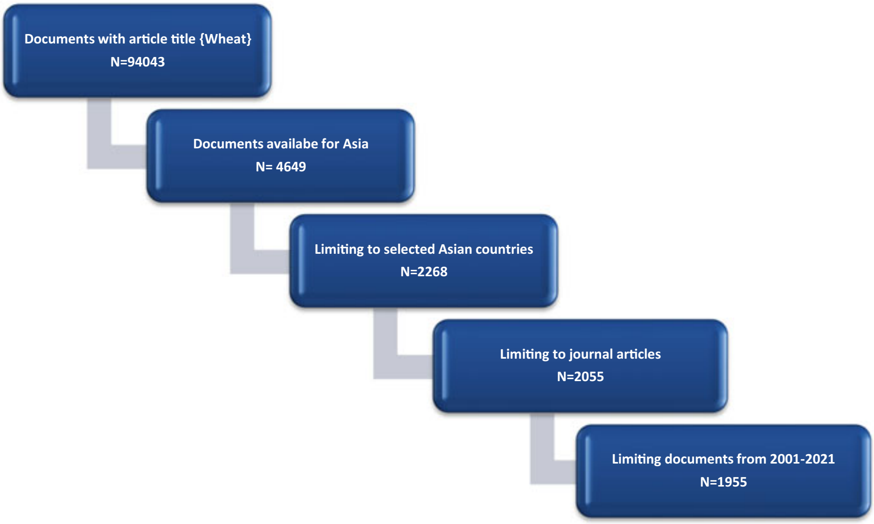


Fig. 3.5 Steps in retrieving research documents from Scopus (Top-down)

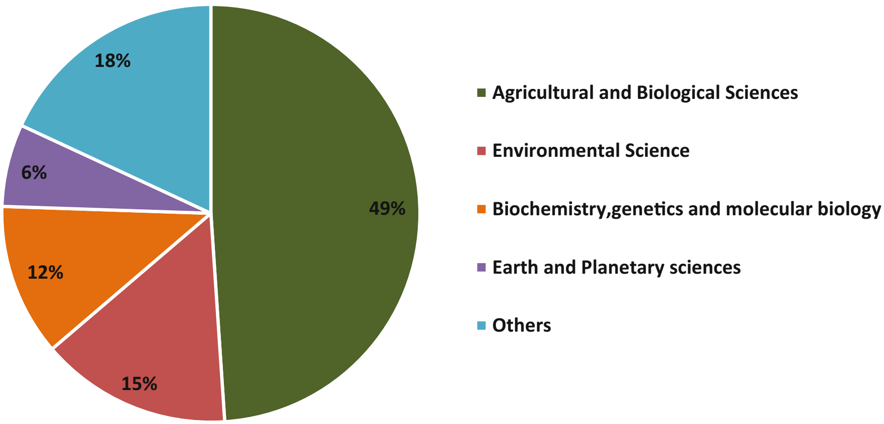


Fig. 3.6 Subject areas of wheat research in Asian countries

molecular biology and others. The other category (18%) included subject areas like social sciences, multidisciplinary, immunology and microbiology.

Bibliographic coupling among the countries was performed to see the research collaboration within Asia (Fig. 3.7). Countries with a minimum level of 10 documents and 100 citations were selected as a basis to perform the analysis. The strongest research collaboration among Asian countries was found to exist between India and China representing a total link strength of 9164, followed by India and Pakistan with a total link strength of 7130. Overall, the analysis on bibliometric study explicitly indicated that India is the most ideal country for

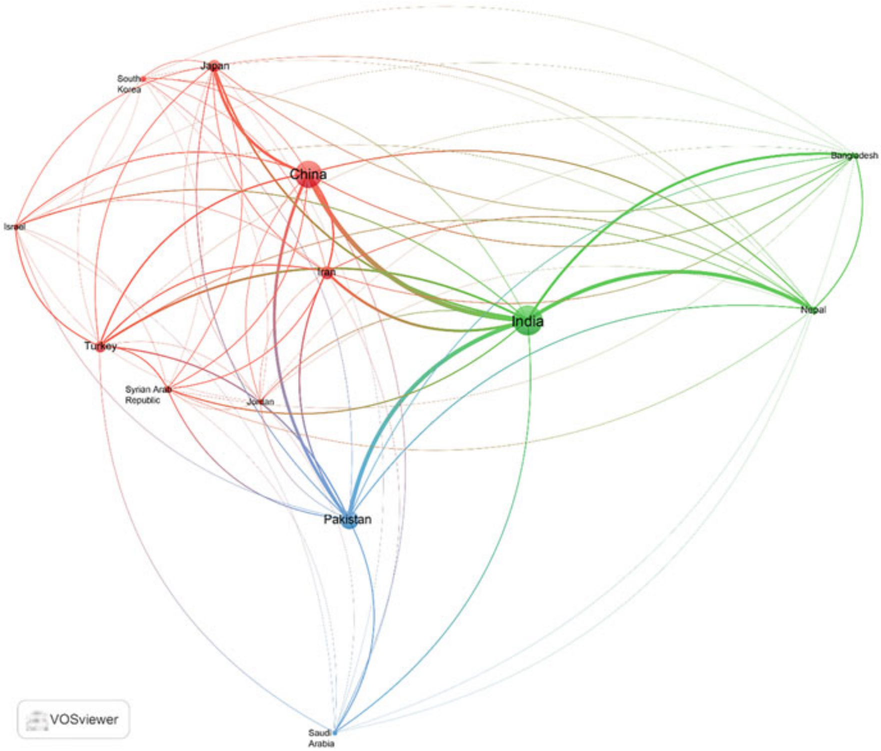


Fig. 3.7 Bibliographic coupling among Asian countries

collaboration in the field of wheat research with a total link strength of 33,848, followed by China (21,195) and Pakistan (15,492). Link strength for a majority of the countries were more than 600 which shows a high degree of research collaboration among Asian countries.

Citation analysis was performed to know the research impact among Asian countries. Countries with a minimum of 10 documents and 100 citations were selected as a basis to perform the analysis. Citation analysis indicates that China received the highest number of citations but with a low link strength of 236, while India showed the highest link strength of 465. This implies that India's research has been cited by a larger number of countries. Density visualization analysis showed that India, China and Pakistan were doing highly impactful wheat research among Asian counties.

Bibliographic coupling among the research organizations was also performed to know the extent of collaboration in wheat research. For this at least 5 documents with a minimum of 100 citations were selected for the analysis. It was found that CIMMYT, South Asia Regional Office, is having the strongest collaboration among countries with a total link strength of 689. The overall bibliometric analysis indicates the progress of research in Asian countries for the recent two decades.

3.7 Research Priorities for Wheat in Asia

Wheat, being and continue to be one of the staple foods for a majority of Asians, the importance of roadmap for wheat research has to be felt by the national research organization and their partners. Asian countries have benefitted immensely from the public research investment, and hence it should occupy the priority position in their strategic and vision documents. In the context, this section outlines the research priorities to underpin the pathway of developing sustainable wheat improvement in Asian countries to cater the regional as well as global demand. While improving the potential yield level becomes customary, future thrust has to be given for quality, nutrition and sustainable production utilizing the advances in cutting-edge sciences followed by outreach through innovative extension models. The possible research advisories are charted under four sections—crop improvement targeting yield and quality enhancement, resource management targeting sustainable farming practices, crop protection through integrated management of pests and diseases including transboundary threats and transfer of technology especially in the new-normal agriculture targeting to reach maximum stakeholders at a minimum cost (Fig. 3.8).

- **Crop Improvement:** A substantial amount of research investment and resources are being spent on crop improvement, which very well gets reflected in varietal spectrum and productivity trend. Green Revolution is one such benefit derived from the adoption of high-yielding varieties, a tangible impact of public research

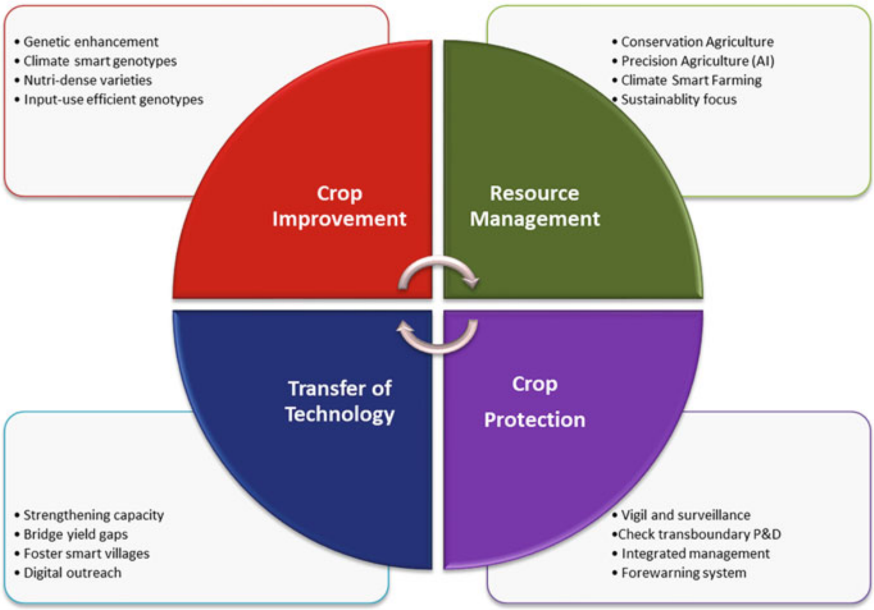


Fig. 3.8 Research priorities for wheat in Asia

investment. The agenda for researchers from crop improvement is not only to produce more wheat but also to enrich wheat grains with higher nutritional value. The success case of All India Coordinated Research Project (AICRP) on wheat which resulted in 725.45% growth in production since 1964–1965 (Sendhil et al. 2019) can be replicated to the rest of the Asian countries wherein public research holds the top slot. South Asia being one of the major contributors to wheat production, Kumar et al. (2010) suggested for 1–1.10% growth in research investment to attain 1% annual growth in wheat productivity and higher allocation of resources to Bangladesh. Grain yield being the most preferred trait by the farmers and researchers, thrust should be given for developing climate resilient, stress (biotic and abiotic)-tolerant varieties without any yield compromise. To attain this, a new emphasis should be given to pre-breeding to broaden the genetic base, as the basic principle of plant breeding is creation of variability to enable selection of the desirable genotypes. Currently, the world is heading towards digitization of breeding programmes, and in the context of increasing efficiency, the national breeding programmes in Asian countries need to be digitized to strengthen their research system. The advances in cutting-edge sciences like molecular breeding, biotechnology, bioinformatics and nanotechnology have to be harnessed and complemented with conventional breeding efforts. Integration of modern breeding tools/strategies (CRISPR-Cas9, double haploids, marker-assisted recurrent selection, targeted mutagenesis, genome-wide selection, speed breeding and genomic selection) with conventional national varietal development programmes should be further strengthened to accelerate the genetic gains. The ultimate aim of the crop improvement is to break the yield barrier (s) and to harness the real genetic potential by manipulating the genetic and/or breeding components, which shall be facilitated through better understanding of physiological traits in combination with environmental interaction (Wheat Initiative 2019). Such integration will help realize better yield potential especially under resource-limited environments.

Historically, the focus of breeding programmes across the globe has been to enhance the productivity per se to feed the increasing population. In countries where self-sufficiency in food grains has been achieved, focus has shifted to better quality. It is evident by initiation of mega ambitious research programme named ‘Biofortification Challenge Program (BCP)’ by CGIAR and later renamed as ‘HarvestPlus’ which led in the development of many nutri-rich wheat varieties in the direction of malnutrition containment (Sendhil et al. 2020a). Similarly, many Asian countries including India launched network like Consortia for Research Platform (CRP) on ‘Biofortification’. Before the last year, five biofortified wheat varieties were released in different countries of South Asia with elevated levels of Zn (Bari Gom 33 in Bangladesh, Zinc Shakti (Chitra), WB02 and HPBW-01 in India and Zincol-2016 in Pakistan) (Velu et al. 2015). In 2020, five such varieties were released in Nepal. Breeding for quality is a tedious, cost-intensive and time-consuming process and has not attracted priority in many countries. However, a reason for the increased demand for wheat is because of wheat-based multiple products for the end-users. Future research programmes in breeding should align with the demands of different stakeholders in the wheat value chain, i.e., farmers (bold and plump grain), millers (test weight and flour yield), food processors (processing quality) and consumers (end-use and nutritional quality).

- **Resource Management:** Increasing the wheat productivity is supported by the optimal use of resources though improved agronomic practices in a system approach (FAO 2009, 2017). Hence, the research agenda for resource management should focus on tillage-environment interactions (location specific) and studies on optimizing the resources like water and nutrients that result in higher technical efficiency. In the context of climate change, adverse impacts on wheat production, three research outcomes were suggested by Sendhil et al. (2016), namely, policies to counter yield sensitivity, developing climate smart wheat production practices and contingent adaptation strategies to the weather anomalies encountered by the crop during growth season. Since climate change has put the farm management decisions at stake, research should focus on developing crop advisories (country-specific and region-specific) especially for the yield-sensitive crop growth stages using crop modelling. Research should target on next-generation resource conservation techniques like using artificial intelligence in input application (time and method), especially for resource-limited regions. Resource management should aim in the refinement and upscaling of climate-smart technologies like drip irrigation for effective utilization of scarce resources. Drip irrigation is already being used in large scale in vegetables and horticultural crops but not in cereals due to cost and operational difficulties. Research also should focus in the development of user-friendly and cost-effective machineries for small land-holdings in Asia. Large-scale deployment of machineries will further decrease the yield gaps and relieves the dependency on labour for various farm operations. More research are also to be conducted to re-validate various farm practices to replace the conventional monocropping systems of major wheat-growing regions of Asia. Also, more emphasis should be given on the development of robust tools/methods to map the wheat-growing areas for need-based input application.
- **Crop Protection:** The most serious disease of wheat is the three rusts. Hence, delivering rust-resistant varieties should be the utmost priority (Joshi et al. 2011) for wheat researchers engaged in breeding and crop protection. The dynamics of pest-disease and crop is co-evolved in nature; therefore emerging pests and diseases remain a serious concern for the researchers and farmers. Conventionally, such threat can be managed by identification of new genes that are resistant to the particular pest and/or disease from a pool of genetic resources. Identification should be followed by deployment by taking consideration of pathogen-environment interaction. Alternatively, an international system can be established (Wheat Initiative 2019) to serve the Asian wheat-growing economies by integrated management of pests and diseases. There must be an efficient system which forewarn (through modelling and prediction) the incidence of major pests and diseases using big data analytics. For instance, India tackled the incidence of wheat blast in Bangladesh by taking strenuous efforts in successful mitigation of the disease threat through pre-emptive breeding and surveillance programme by

initiating a strong coordination among Indian Council of Agricultural Research, Department of Agricultural Research and Education, Department of Agriculture & Farmers Welfare, State Department of Agriculture, state government (mainly West Bengal) and international organizations like CIMMYT which facilitated screening of germplasm in Bolivia and Bangladesh.

- **Transfer of Technology:** All nations urgently require regional collaboration (Joshi et al. 2013) and an active transfer of technology (ToT) system capitalizing modern tools and techniques to reduce the information and knowledge gap that gets translated into bridging the yield gaps as well as addressing the yield sensitivity (Sendhil et al. 2014, 2016). Research on ToT should focus on developing mobile apps in local languages, decision support system and blockchain-enabled seed tracker[5] especially in regions where adoption rate is low. It should also bring about awareness among farmers of new improved varieties and production technologies for yield as well as income enhancement (Sendhil et al. 2017; Kumar et al. 2014). Faster seed dissemination is important and can be done through pre-release seed multiplication as demonstrated in case of Ug99-resistant varieties and six countries of Asia and Africa (Joshi et al. 2011). Further, alternate research and development avenues that can result in visible impact like 'seed village', 'climate-smart village' and 'nutri-smart village' have to be fostered (upscaling and outscaling).

Clearly, the research priorities discussed across programmes or dimensions should aim for delivering sustainable wheat production catering the demand of the multiple stakeholders under the unified framework (research-extension-policy-institutions) furnished in Fig. 3.9 (Singh et al. 2016). In addition, institutions like wheat market should be supported with region-specific procurement policies (Sendhil et al. 2020b).

3.8 Conclusions

Food being the basic need accounts for four-fifth of the calorie intake. Undoubtedly, food intake and nutrition security have a strong inter-linkage and largely influence human as well as economic development. Wheat, a nutri-rich cereal, holding a major chunk of the production, trade and consumption basket of Asians underpins strategic research owing to the burgeoning population and increasing demand for wheat and wheat-based products. In the realm of climate change that largely impacts the wheat output, along with other production constraints and emerging challenges like declining per capita farm land, reduced resource base, transboundary pests and diseases, declining share of R&D investment and changing consumer preferences calls for pragmatic and sustainable wheat production pathway to ensure zero hunger as

[5] https://www.rtb.cgiar.org/news/seed-tracker-how-one-app-can-enhance-seed-systems-for-many-crops/

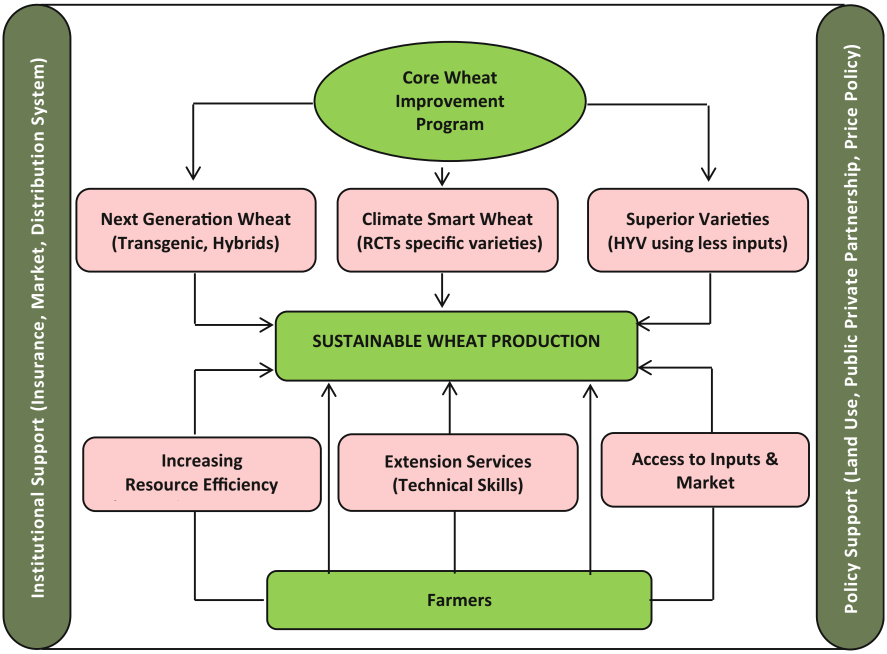


Fig. 3.9 Framework for sustainable wheat production (Source: Singh et al. 2016)

committed under the SDGs. Asia comprising many developing economies have an enormous potential to increase the wheat productivity, but the challenge is how to do this in a sustainable manner when resources are really limited. Perhaps, the possible pathway is to have a concerted effort and synergy between national research-extension-policy-institutions under a unified framework. To deliver the impact, wheat-growing countries in Asia should frame the research agenda and must set priorities for allocation of the resources to reinforce interventions and innovations that would result in overall wheat improvement.

References

Aggarwal PK (2009) Global climate change and Indian agriculture—case studies from the ICAR network project. Indian Council of Agricultural Research New Delhi. http://www.indiaenvironmentportal.org.in/files/ICAR-nov09.pdf

Aryal JP, Sapkota TB, Khurana R et al (2019) Climate change and agriculture in South Asia: adaptation options in smallholder production systems. Environ Dev Sustain 22:5045–5075

Bhatt R, Kukal SS, Busari MA et al (2016) Sustainability issues on rice-wheat cropping system. Int Soil Water Conserv Res 4:64–74

Braun H (2012) Regional scenario of wheat in Asia Proceedings of the regional consultation on improving wheat productivity in Asia, Bangkok, Thailand

Breiman A, Graur D (1995) Wheat evolution. Isr J Plant Sci 43(2):85–98

Chand R (2001) Wheat exports: little gain. Econ Polit Wkly 36(25):2226–2228

Chowdhury AK, Saharan MS, Aggrawal R, Malaker PK, Barma NCD, Tiwari TP, Duveiller E, Singh PK, Srivastava A, Sonder K, Singh RP, Braun HJ, Joshi AK (2017) Occurrence of wheat blast in Bangladesh and its implications for South Asian wheat production. Indian J Genet Plant Breed 77:1–9. https://www.isgpb.org/documents/archive/1-1-9-apurba-kumar-chowdhury-2.pdf

Enghiad A, Ufer D, Countryman AM, Thilmany DD (2017) An overview of global wheat market fundamentals in an era of climatic concerns. Int J Agron. https://doi.org/10.1155/2017/3931897

FAO (2009) High level expert forum—how to feed the world in 2050. Global agriculture towards 2050. Food and Agriculture Organization Rome

FAO (2011) Food and Agriculture Organization. https://www.fao.org/statistics/en/

FAO (2017) The future of food and agriculture—trends and challenges. Food and Agriculture Organization Rome

FAOSTAT (2020) Food and Agriculture Organization Statistics. https://www.fao.org/faostat/en/#data/QCL

Fischer RA, Byerlee DB (1991) Trends of wheat production in the warmer areas: major issues and economic considerations. In: Wheat for the Non-traditional warm Areas. Proc. of Conf., Iguazu, Brazil, 29 Jul.–3Aug. 1990. CIMMYT, Mexico, DF. pp 3–27

Fujisaka S, Harrington L, Hobbs P (1994) Rice-Wheat in South Asia: systems and long-term priorities established through diagnostic research. Agric Syst 46(2):169–187. https://doi.org/10.1016/0308-521X(94)90096-X

Hobbs PR, Morris ML (1996) Meeting South Asia's future food requirements from Rice–Wheat cropping systems: priority issues facing researchers in the post-green revolution Era. NRG paper 96–01, CIMMYT, Mexico, DF

IAEA (2009) Protecting Wheat harvests from destruction. https://www.iaea.org/resources/newsarticle/protecting-wheat-harvests-from-destruction

Joshi AK, Chand R, Arun B, Singh RP, Ortiz R (2007a) Breeding crops for reduced-tillage management in the intensive, rice-wheat systems of South Asia. Euphytica 153:135–151

Joshi AK, Mishra B, Chatrath R, Ferrara GO, Singh RP (2007b) Wheat improvement in India: present status, emerging challenges and future prospects. Euphytica 157(3):431–446

Joshi AK, Azab M, Mosaad M, Moselhy M, Osmanzai M, Gelalcha S, Bedada G, Bhatta MR, Hakim A, Malaker PK, Haque ME, Tiwari TP, Majid A, Kamali MRJ, Bishaw Z, Singh RP, Payne T, Braun HJ (2011) Delivering rust resistant wheat to farmers: a step towards increased food security. Euphytica 179:187–196

Joshi AK, Singh RP, Payne T, Braun HJ (2013) Regional collaboration for wheat in Asia. In: Paroda R, Dasgupta S, Mal B, Singh SS, Jat ML, Singh G (eds) Proceedings of the regional consultation on improving wheat productivity in Asia, Bangkok, Thailand 26–27 Apr 2012, 224 p

Kumar P, Mruthyunjaya, Chand R (2010) Food security, research priorities and resource allocation in South Asia. Agric Econ Res Rev 23:209–226

Kumar A, Sendhil S, Singh R et al (2014) Yield gaps in wheat production—magnitudes, sources and narrowing them for socio-economic change. In Wheat: recent trends on production strategies of wheat in India. JNKVV, Jabalpur and ICAR-IIWBR, Karnal, pp 165–175

Kumar S, Sendhil R, Mishra CN, Chatrath R (2020) Vulnerability of wheat production to climate change. In: Improving cereal productivity through climate smart practices. Woodhead Publishing (Elsevier). https://doi.org/10.1016/B978-0-12-821316-2.00014-5

Maitu M, Ankerst DP, Manzel A (2017) Interactions between temperature and drought in global and regional crop yield variability during 1961-2014. PLoS One 12:e0178339

Malaker PK, Barma NCD, Duveiller E, Tiwari TP, Collis WJ, Singh PK, Joshi AK, Singh RP, Braun HJ, Peterson GL, Pedley KF, Farman M (2016) First report of wheat blast caused by Magnaporthe oryzae pathotype Triticum in Bangladesh. Plant Dis 100:2330. https://doi.org/10.1094/PDIS-05-16-0666-PDN

Nayak A, Huchaiah L (2019) Trends in agricultural research and development in India. Res J Chem Environ Sci 7(4):06–11

OrtiZ R, Sayre KD, Govaerts B et al (2008) Climate change: can wheat beat the heat? Agric Ecosyst Environ 126:46–58
Pathak H, Aggrawal PK, Peng S et al (2003) Trends of climatic potential and on-farm yields of rice and wheat in Indo-Gangetic Plains. Field Crop Res 80:223–234
Rajaram S (2012) Strategy for increasing wheat productivity. Proceedings of the regional consultation on improving wheat productivity in Asia, Bangkok, Thailand
Ramadas S, Kumar TK, Singh GP (2019) Wheat production in India: trends and prospects. In: Recent advances in grain crops research. Intech Open. https://doi.org/10.5772/intechopen.86341
Ramdas S, Singh R, Sharma I (2012) Exploring the performance of wheat production in India. J Wheat Res 4(2):37–44
Rosegrant MW, Agcaoili M (2010) Global food demand, supply and price prospects to 2010. International Food Policy Research Institute, Washington, DC
Sendhil R, Singh R, Ramasundaram P, Kumar A, Singh A, Sharma I (2014) Yield gap in wheat: approach, quantification and resetting research priorities in India. J Wheat Res 6(2):138–149
Sendhil R, Ramasundaram P, Meena RP et al (2016) Tracking the yield sensitivity of rice-wheat system to weather anomalies. Natl Acad Sci Lett 39(6):401–405
Sendhil R, Kumar A, Singh S et al (2017) Framework for doubling the income of wheat producers' by 2022: trends, pathway and drivers. Indian J Econ Dev 13:1–8
Sendhil R, Kumar A, Singh S, Singh GP (2019) Wheat production technologies and food security: the nexus and prospects. In: Pouchepparadjou A, Umamaheswari L, Devi S (eds) Ascertaining food security through livelihood enriching interventions: challenges and opportunities, pp 7–15
Sendhil R, Vellaichamy S, Ramasundaram P, Kumar A, Singh S (2020a) Biofortification for enhancing nutritional outcomes and policy imperatives. In: Wheat and barley grain biofortification. Woodhead Publishing (Elsevier). https://doi.org/10.1016/B978-0-12-818444-8.00013-4
Sendhil R, Ramasundaram P, Subash SP, Ram S, Kumar A, Singh S, Singh GP (2020b) Policy imperatives for wheat procurement. Policy Paper 1. ICAR-Indian Institute of Wheat and Barley Research, Karnal, pp 1–26
Singh RP, Hodson DP, Huerta-Espino J, Yue J et al (2008) Will stem rust destroy the world's wheat crop? Adv Agron 98:271–309
Singh GP, Gupta RK, Sendhil R (2016) Trends and potential pathways for sustainable wheat production in India. In: 55th All India Wheat & Barley Research Workers' Meet, CCSHAU, Hisar, pp 21–24
Svanidze M, Gotz L, Djuric, Glauben T (2019) Food security and the functioning of wheat markets in Eurasia: a comparative price transmission analysis for the countries of Central Asia and the South Caucasus. Food Secur 11:733–752
Timsina J, Wolf J, Guilpart N et al (2018) Can Bangladesh produce enough cereals to meet future demand? Agric Syst 163:36–44
USDA (2020) United States Department of Agriculture. https://usda.library.cornell.edu/concern/publications/5q47rn72z?locale=en
Velu G, Singh RP, Balasubramaniam A, Mishra V, Chand R, Tiwari C, Joshi A, Virk P, Cherian B, Wolfgang P (2015) Reaching out to farmers with high zinc wheat varieties through public-private partnerships—an experience from eastern-Gangetic plains of India. Adv Food Technol Nutr Sci 1:73–75
Wheat Initiative (2019) An international vision for wheat improvement. https://doi.org/10.5073/20190702-122315