Land Use Policy 82 (2019) 1–12

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Alternative use of wheat land to implement a potential wheat holiday as wheat blast control: In search of feasible crops in Bangladesh

Khondoker Abdul Mottaleb[a,*], Pawan Kumar Singh[b], Xinyao He[b], Akbar Hossain[c], Gideon Kruseman[d], Olaf Erenstein[e]

[a] Socioeconomics Program, CIMMYT (International Maize and Wheat Improvement Center), México-Veracruz Km. 45, El Batán, Texcoco, C.P. 56237, México
[b] Wheat Pathology, Global Wheat Program, CIMMYT, Mexico
[c] Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur-5200, Bangladesh
[d] Ex ante and Foresight Socioeconomics Program, CIMMYT, Mexico
[e] Socioeconomics Program, CIMMYT, Mexico

ARTICLE INFO

Keywords:
Alternative crops
Ex-ante
Feasibility
Wheat blast
Wheat
Wheat holiday
Bangladesh

ABSTRACT

The first occurrence of wheat blast in Bangladesh was confirmed in wheat (*Triticum aestivum*) fields in February 2016 and re-occurred in the subsequent years. This study explores the potential of alternative use of current wheat land as a strategy to combat the disease. Economically feasible alternative crops would need to be cultivated in the current wheat area by implementing a potential 'wheat holiday' – that is discontinuing wheat cultivation for a few years – be it in the 10 blast affected districts, in blast vulnerable districts or the entire country. An *ex-ante* economic assessment procedure is applied to examine the potential economic gains (losses) of alternative wheat land use. Results indicate maize, lentils, onions and garlic show potential as feasible alternatives if done as a portfolio combination and with adequate support to ameliorate and ease the transition; whereas *boro* rice, gram and potato do not appear feasible. Still, considering market volatility, overall food security and logistic challenges, the findings do not support a potentially comprehensive, strict and permanent 'wheat holiday' across the entire country. Instead, the study calls for research funding for disease epidemiology and forecasting, as well as the development and dissemination of blast-tolerant wheat varieties and complementary practices targeted at Bangladesh and the broader South Asian setting as a more sustainable and feasible solution to combat and manage wheat blast.

1. Introduction

Wheat blast caused by the fungus *Magnaporthe oryzae* pathotype *triticum* (MoT) is one of the most devastating wheat diseases with near complete yield losses (Urashima et al., 2009). The disease was first officially reported in Parana State, Brazil in 1985 (Igarashi et al., 1986). In 2005, it reduced grain yield by 14–32% in Brazil, even after two applications of fungicides (Urashima et al., 2009). The disease mainly emerged in the humid and warmer zones of Brazil, Bolivia, Paraguay, and northeastern Argentina, covering up to 3 million ha (Duveiller et al., 2011, 2016).

In February 2016, wheat blast was confirmed in Bangladesh, South Asia (Malaker et al., 2016; Callaway, 2016; Islam et al., 2016). In that year, wheat blast affected nearly 15,000 ha of wheat land in eight districts of Bangladesh: Barishal, Bhola, Chuadanga, Jashore, Jhenaidah, Kusthia, Meherpur and Pabna (3.5% of its total wheat area of 437,000 ha). The blast reduced wheat yield by 5–51% in the affected fields (Islam et al., 2016). In 2016-17 wheat season, despite unfavorable weather for the disease's development (less humid and less rain), the wheat blast was again reported in Bangladesh in the original districts, as well as in two new districts, Rajshahi and Faridpur. It indicates that wheat blast is now an established disease in Bangladesh with no immediate prospects for its eradication. In a recent study, Mottaleb et al., (2018a), applying the climate-analog analysis procedure, demonstrate that, out of 0.43 million ha wheat land in Bangladesh, 0.28 million ha (65%) is vulnerable to wheat blast, spread over 45 districts of

* Corresponding author.
E-mail addresses: k.mottaleb@cgiar.org (K.A. Mottaleb), Pk.Singh@cgiar.org (P.K. Singh), X.He@cgiar.org (X. He), akbarhossainwrc@gmail.com (A. Hossain), G.KRUSEMAN@cgiar.org (G. Kruseman), O.Erenstein@cgiar.org (O. Erenstein).

https://doi.org/10.1016/j.landusepol.2018.11.046
Received 20 August 2018; Received in revised form 22 November 2018; Accepted 23 November 2018
0264-8377/ © 2018 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/BY/4.0/).

Bangladesh.[1] In fact out of a regional total 40.85 million ha of wheat area in Bangladesh, India and Pakistan, 6.99 million ha (17.1%) is vulnerable to wheat blast (Mottaleb et al., 2018a), including parts of the Gangetic plains, a densely populated and intensively cultivated area (Timsina et al., 2010; Erenstein and Thorpe, 2011). A 5% reduction in wheat production due to a potential spread of wheat blast in the vulnerable area can reduce wheat production by 886 thousand metric ton worth USD 132 million (Mottaleb et al., 2018a).

Bangladesh and India share a long international border. The West Bengal State of India borders Bangladesh and has a similar agro-climatic and cropping pattern, particularly in the border districts. As a preventive measure, the West Bengal state government has banned wheat cultivation within five kilometers from the Bangladesh border (Government of India (GoI), 2017). In addition, the government has recently implemented a preventive 'wheat holiday' by banning wheat cultivation in Murshidabad and Nadia districts for three years (Government of India (GoI, 2017).

In Bangladesh, the government discourages farmers from cultivating wheat in the blast-affected districts (Bangladesh Bureau of Statistics (BBS, 2018). In the absence of commercially available blast-tolerant/resistant wheat varieties for farmers, a potential control measure could be to suspend wheat production in selected areas (e.g., across Bangladesh, or at least in the blast vulnerable or currently blast-affected districts), i.e., a nominal 'wheat holiday'. However, before implementing a wheat holiday policy, it is imperative to suggest economically feasible alternative crops to the resource-poor smallholder farmers. In India, the government has suggested cultivating legumes and oilseeds instead of wheat in the border districts of West Bengal (Government of India (GoI, 2017). In Bangladesh, there is no such guidance or rigorous study to examine economically viable alternative crops that can be suggested to the farmers.

The present study examines the economic feasibility of cultivating alternative crops to potentially substitute wheat in entire Bangladesh or only in the blast vulnerable and blast affected districts, in the context of a possible 'wheat holiday' policy to combat wheat blast. Wheat occupies 2.9% of the total cropped area and contributes 3.7% to the total output of major cereals in Bangladesh (Bangladesh Bureau of Statistics - BBS, 2018). In 2016-17 wheat season, 1.31 million tons of wheat was harvested from 415.3 thousand ha of land (BBS, 2018). The current consumption of wheat in Bangladesh is 7.5 million metric tons in total with an annual consumption increase of more than 26% from 1961 to 2018 (USDA, 2018), with Bangladesh already heavily reliant on imports. A 'wheat holiday' policy in Bangladesh could ostensibly prohibit domestic wheat production for a few years, encourage the cultivation of alternative crops to curtail (and possibly eradicate) the wheat-blast inoculum. It would increase the reliance on imports, and any such policy should closely consider its viability, including the various dimensions for food security and well-being of affected, generally resource-poor, farmers. This study primarily assesses the expected net returns of the major alternate winter crops to wheat in Bangladesh applying an *ex-ante* impact assessment procedure. The study is an exercise to raise awareness of the possible implications to policymakers and stakeholders.

The study is organized as follows: Section 2 explains the wheat-blast-host-pathogen system; Section 3 explains the *ex-ante* economic estimation procedure; Section 4 examines the current wheat sector (area, production and consumption) in Bangladesh and the economic viability of the alternative crops; and Section 5 concludes with a discussion and policy implications.

[1] Out of 45 blast vulnerable districts in Bangladesh (Mottaleb et al., 2018a,), wheat is not cultivated in three hilly districts (Bandarban, Khagrachari, Rangamati). Therefore, in this study, we considered 42 districts, of which 32 are identified vulnerable and 10 are already affected by wheat blast.

2. Wheat-blast-host-pathogen system

Ceresini et al. (2018) linked the blast outbreak in Bangladesh in 2016 with a series of wheat imports from Brazil. The introduction of MoT from South America to Bangladesh thereby appears associated with the seed borne nature of the disease (Urashima et al., 2009) and the failure of quarantine measures (Islam et al., 2016). As, MoT can survive for up to 22 months in seeds (Reis et al., 1995), strict transport and quarantine measures are needed to prevent wheat grains and seed moving from the infected regions to non-infected areas, even as a grain because farmers may use it as seed.

In addition to being seed borne, MoT can also be airborne. Urashima et al., (2007) noticed that MoT spores could be blown by the wind to at least one kilometer away, although their study focused on the asexual spores (conidia) of MoT, which are heavier than the sexual spores (ascospores) (Urashima et al., 2005). The lighter ascospores may thus contribute to the long-distance dispersal of MoT (Maciel et al., 2014). Most farmers in Bangladesh and West Bengal, India are smallholders, and wheat is the second major staple food crop after rice, potentially facilitating the within-country spread, and the long border and similar agro-ecology could facilitate cross-border spreading to West Bengal and beyond.

Potential wheat-blast control measures need to take into account the various survival mechanisms of MoT, including on non-wheat host plants and plant debris. Earlier studies in South America have shown that MoT has a wide range of alternate hosts, including various crops (e.g. barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), triticale (*X. triticosecale* Wittmack), common millet (*Panicum mileaceum* L.), oats (*Avena sativa* L.), maize (*Zea mays* L.), and sorghum (*Sorghum vulgare* L.)) (Urashima et al., 2005), and various weeds (e.g., *Cenchrus echinatus*, *Eleusine indica*,*Digitaria sanguinalis*, *Brachiaria plantaginea*, *Echinochloa crus-galli*, *Pennisetum setosum*, *Setaria geniculata*, *Hyparrhenia rufa,* and *Rhynchelytrum roseum*) (Kohli et al., 2011). The alternate hosts in South Asia still need confirmation, but could well include many South Asian weed species, as well as some common crop species, such as maize. Thus, any consideration of a wheat holiday would also need to consider the possible suspension of other susceptible crop species. Also, surveillance of blast-like symptoms on weed species is needed, with the timely control of any weed species that infected by MoT. Furthermore, MoT appears to survive on crop residues (Islam et al., 2016; Cruz and Valent, 2017), calling for appropriate crop-residue management and undermining practices such as conservation agriculture that advocate the retention of crop debris in the field.

To control the wheat blast after the 2015-16 epidemic, the Bangladesh government started discouraging wheat production in the blast-affected districts (BBS, 2018). Farmers may also be discouraged from cultivating wheat due to the potential financial losses associated with wheat blast occurrence. Consequently, wheat areas in Faridpur, Kushtia, Chuadanga, Meherpur, Pabna and Rajshahi districts were reduced from 143,226 ha in 2014-15 to 102,790 ha in 2015-16 (BBS, 2016, 2018). The national average wheat yield in the 2015-16 season was reduced by 1.78% compared to the 2014-15 season (BBS, 2016), although it rebounded in 2016-17 (increasing by 4.19% compared to 2015-16 wheat season, BBS, 2018). Despite the discouragement of wheat cultivation in the blast affected regions, and unfavorable weather conditions for blast (less humidity and rain), wheat blast still re-emerged in 2016-17 in all eight previously-affected districts (Islam et al., 2016), as well as extended into two new districts Rajshahi and Faridpur (Fig. 1).

The pathogen now appears endemic in the country with demonstrated persistence and rapid dispersal even under unfavorable climatic conditions. For successfully combating wheat blast, further research on disease epidemiology and forecasting, resistance screening, and effective management strategies are needed, particularly in the context of Bangladesh and South Asia.

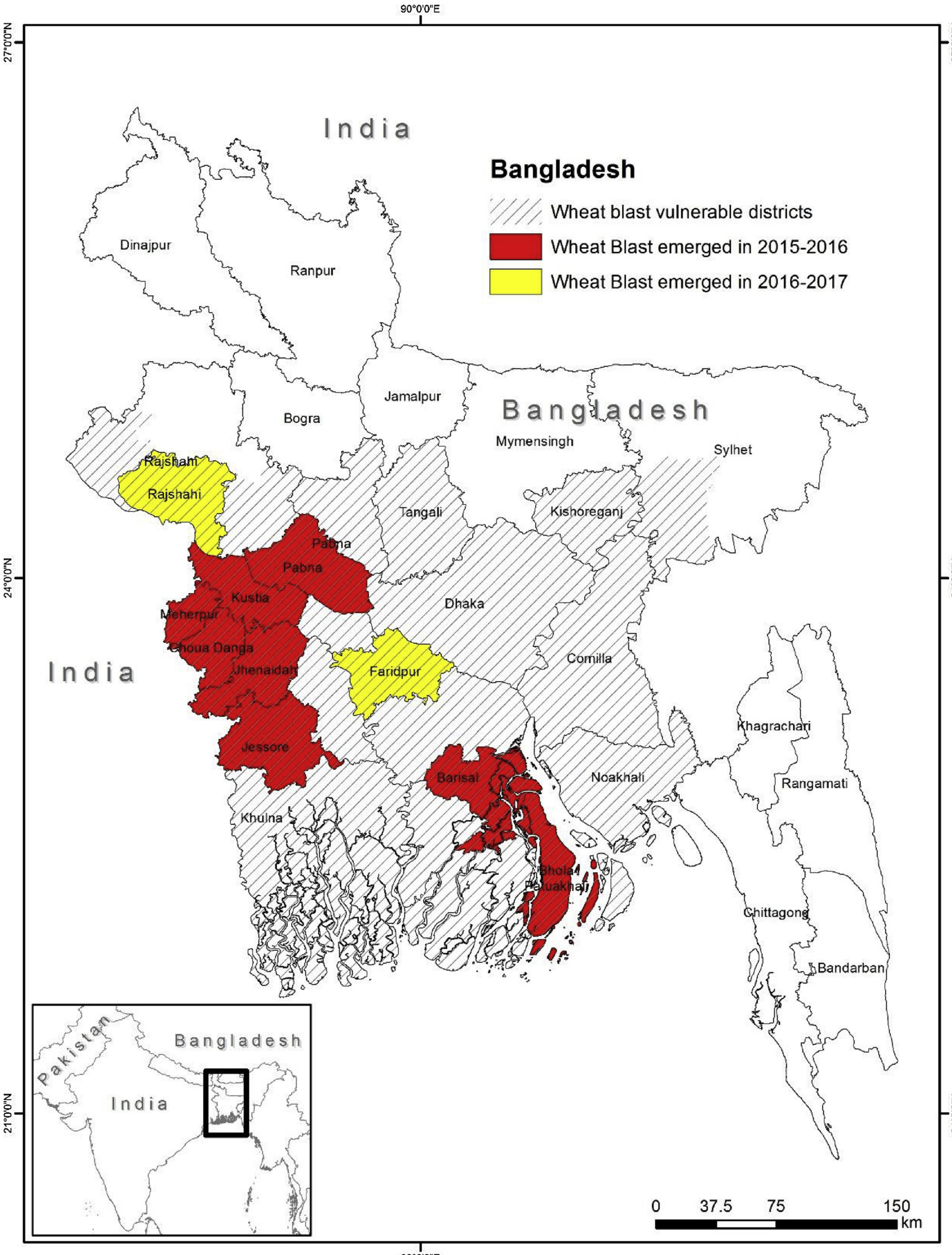

Fig. 1. Blast affected districts in 2015/16, and 2016/17 seasons, and blast vulnerable districts in Bangladesh identified by Mottaleb et al., (2018a).
Source: Authors' based on Islam et al., (2016); CIMMYT (2017) and Mottaleb et al., (2018a).

3. Ex-ante assessment methods

As, MoT can survive on seeds for up to 22 months (Reis et al., 1995), a possible wheat blast control measure would be to introduce a 'wheat holiday' policy for at least two years. In India, the state government of West Bengal has banned wheat cultivation in Murshidabad and Nadia districts for three years (Government of India (GoI, 2017). This study estimates the expected gross and net margins of seven alternative crops to wheat to examine the economic viability of each crop as a replacement of wheat during any eventual 'wheat holiday' period in Bangladesh. Wheat is only grown in the *Rabi* (dry, relatively cool winter season) season in Bangladesh. As alternate crops, we consider only crops that can realistically be grown in this cooler season based on agronomic characteristics. We particularly include crops that are currently already being grown in the winter season: *boro* rice (*Oryza sativa L.*), maize (*Zea mays L.*), lentils (*Lens culinaris L.*), gram (*Cicer arietinum L.*), onions (*Allium cepa L.*), garlic (*Allium sativum L.*) and potatoes (*Solanum tuberosum L.*). In the case of rice, there are three rice seasons in Bangladesh, and we have only considered the boro rice season, which falls within the wheat season.

We applied a simple *ex-ante* estimation process to examine the economically feasible alternative crops. In the process, we first compile the production economics data for the triennium ending (TE) 2016-17. Among the production economics data, yield (ton/ha), area (ha), and production (metric ton) at the district level are collected from BBS (2016, 2018). We also computed the average prices of the sampled crops (TE2016-17, from BBS, 2016, 2018). The per hectare production costs (single year) information is collected from various sources. Currently, out of 64 districts in Bangladesh, wheat is cultivated in 60 districts in 2015-16, except the coastal district of Cox's Bazar, and hilly districts of Bandarban, Khagrachari and Rangamati (BBS, 2018). For the substitution scenarios, we assume a complete replacement of the current wheat area at the district level by the sampled alternate crops. For each alternate crop, the current average district level yield (t ha^{-1}) of the crop is multiplied with the current wheat area at the sampled district and with the current market price of the sampled crop to calculate the expected gross return (GR_c) under the substitution scenario. Thus, the expected gross return (GR_c) from each crop under the alternative scenario, assuming a complete replacement of the current wheat area by the alternate crop in a sample district (d), is calculated as follows:

$$GRc = \sum_{d=1}^{60} (\, WA_{d\,TE2016-17}\, X\, Cyield_{TE\,2016-17}\, X\, Pc) \tag{1}$$

where GR_c is the expected gross return of an alternate crop c (= 1—7), $WA_{d\,TE2016-17}$ is the land area (TE 2016-17) under wheat (ha) in district d (d = 1———60), $Cyield_{TE\,2016-17}$ is the district level average yield (metric ton/ha, TE 2016-17) of the alternate crop c and Pc is the domestic market price (TE 2016-17) of the alternate crop c (USD/ton). In this calculation, it is thus implicitly assumed that (1) the alternative crops (*boro* rice, maize, lentils, gram, onions, garlic and potato) can completely replace the current wheat area in the sampled districts in entire Bangladesh; and (2) that the yields and returns of the alternative crops on the entire wheat area in each district would be comparable to those achieved on the actual current areas of the alternate crop in the same district. Based on the assumptions, the expected Gross Margin (*GM*) for each alternative crop *c,* is calculated as follows:

$$GM_c = GR_c - \ (CPH_c\, X \sum_{d=1}^{60} WA_{d\,TE2016-17}) \tag{2}$$

where CPH_c is the per hectare production cost of crop c (USD/ha). The production costs are based on national averages, and we assume the costs are similar across the districts lacking district specific production cost information. Finally, the expected margin net of wheat (ENM_c) of each alternate crop in the substitution scenario is calculated as follows:

$$ENM_c = GM_c - \ GM_w \tag{3}$$

where, ENM_c is the expected net margin from crop c, GM_c is the gross margin of crop c, and GM_w is the wheat gross margin.

To our knowledge, this is the first attempt of examining the economic feasibility of the alternative crops in Bangladesh applying an ex-ante assessment method to combat wheat blast by implementing wheat holiday. To clarify our method, we have developed a concrete example as follows. Chuadanga (Fig. 1) is a wheat blast affected district with current wheat area 4,948 ha and production 14,954 metric ton. At a market price USD 273.3/ton the Gross Return from wheat (GR_w) USD 4.09 million (total product X price). Wheat production cost in Bangladesh is USD 663/ha. It indicates that the current wheat production cost in Chuadanga district is USD 3.28 million (4,948 ha X USD 663). Based on the calculated gross return (GR_w) and total wheat production cost, we calculate the Gross Margin (GM_w) from wheat cultivation in Chuadanga as

Gross return- Production cost = USD 4.09 million - USD3.28 million = USD 0.81million.

As Chuadanga is a wheat blast affected district, we now examine the economic feasibility of producing *boro* rice as a replacement of wheat. The current *boro* rice yield in Chuadanga district is 3.73 ton/ha. If *boro* rice is produced on the current wheat area of Chuadanga district, the additional *boro* production would be 18,461 metric ton (4948 ha current wheat area in Chuadanga X 3.73 - *boro* yield in Chuadanga). With a market price of *boro* rice USD 229.9 /ton, the gross return (GR_{boro}) from *boro* production would be USD 4.24 million. With *boro* production cost USD 1,319/ha the total *boro* production cost under the alternative scenario would be 4948 (current wheat area in Chuadanga) X 1319 (per ha *boro* production cost) = USD 6.52 million. It indicates that the gross margin (GM_{boro}) from replacing wheat by *boro* rice in Chuadanga will be

GM_{boro} = 4.24 (GR_{boro})- 6.52 (total product cost PC_{boro}) = -2.28

The Expected Net Margin ENM_{boro} net of wheat from cultivating *boro* instead of wheat will be

ENM_{boro} = GM_{boro} -GM_w

=-2.28-0.81= -3.09 million USD.

It demonstrates that a replacement of the current wheat area in Chuadanga district by *boro* rice would incur a net loss of USD 3.09 million under the current yield, production cost, and market price scenario. In our estimation process, we have done this exercise for all 60 wheat-producing districts in Bangladesh in assessing the economically feasible alternative crops to wheat.

In the estimation process, scenario 1 considers a wheat holiday for the entire wheat area of Bangladesh. However, considering the administrative and logistics burden of implementing wheat holiday in entire Bangladesh, we developed two more scenarios. Under scenario 2, the economic feasibility of alternative crops is examined assuming a wheat holiday only in 42 blast vulnerable districts identified by Mottaleb et al. (2018a). In scenario 3, a wheat holiday is assumed only in the ten currently wheat blast affected districts. The present analysis otherwise assumes *ceteris paribus*. This includes the assumption of constant prices. The Bangladesh agricultural sector is relatively integrated into the global commodity markets and, for instance, relies on imports to compensate for shortfalls in wheat, maize, lentils, onions and garlic; whereas it is largely self-sufficient in rice and is a net exporter of potatoes. In a more closed economy or with less tradable commodities, the price effects of crop substitution would play an important role. The present study assumes that the current wheat area in Bangladesh is equally suitable for all seven alternative crops compared to the alternative crops current area, which is a strong assumption. Also, the present study did not consider the financial and learning costs of the agronomic practices that farmers need to incur to switch from wheat to other crops, nor the market and value chain costs associated with increased production and potential reversal of trade-flows (net importer

Table 1
Crop sector characteristics for selected crops (averages for triennium ending, TE 2016-17), Bangladesh (base situation).
Sources: [1]BBS (2016, 2018), [2] FAO (2018), triennium average ending 2016; [ı]BBS (2016)

Crop	Cropping season[1]		Area[1]	Yield, production and price[1]		Trade balance (Import (-); export, (+) [2]	
	Sowing	Harvesting	'000, ha	Yield	'000, metric ton (million USD)	Price (USD/ton)	'000 metric ton (million USD)
Wheat	Nov-Dec	Mar-mid-Apr	432.3	2.41	1,336 (365.1)	273.3	−3510 (-870)
Boro rice	mid-Nov to mid-Feb	Apr-Jun	3961.3	3.79	15355.5 (3530.2)	229.9	−663.5 (-260)
Maize	Mid-Oct to late Dec	Early Apr-May	350.0	5.20	2581 (559.2)	216.6[ı]	−652.4 (152.6)
Lentils	Mid-Oct to mid-Nov	Feb- Mar	151.5	0.94	165 (160.4)	973.2	−207.6 (-175.3)
Gram	Mid-Oct- late Nov	Mar-Apr	4.4	0.80	6.4 (4.3)	660.3	−233.2 (-135.3)
Onions	Oct-early Dec	Late Apr-mid-Jun	177.6	6.98	1,769 (786.8)	444.8	−383.7 (-125.8)
Garlic	Mid-Oct to mid-Dec	Mid-Feb-mid-Mar	61.4	4.77	384 (329.1)	856.2	−56.2 (-56.5)
Potatoes	Mid-Sep to Nov	mid-Jan-Mar	482.1	16.70	9648 (1567.8)	162.5	+70.6 (+15.5)

to net exporter).

4. Viability of alternate crops as a wheat replacement

4.1. Wheat

Similar to many other emerging economies in Asia and Africa (Mason et al., 2015; Mottaleb et al., 2018b), the yearly per capita wheat consumption in Bangladesh has increased by 103% from 8.6 to 17.5 kg from 1961 to 2013 (FAO, 2017a). Wheat area increased in Bangladesh to meet growing wheat demand. For a recent comparison, in 2008-09, the total land allocated to wheat was 394.5 thousand ha, and total wheat production in the country was 849 thousand metric tons (BBS, 2011). In 2016-17, the total land allocation to wheat was 415 thousand ha, which was 5% higher than the 2008-09 season, and total production was 1.3 million metric tons, which was 45% higher than the 2008-09 season (BBS, 2011, 2018). The total wheat area in 42 blast vulnerable districts is 261.4 thousand ha (triennium average ending 2016-17), whereas wheat area in the 10 blast affected districts is 141.6 thousand ha (Table 1). The domestic production of wheat in Bangladesh, however, only meets nearly 32% of the total consumption. Hence, to meet the increasing consumer demand, Bangladesh imported 3.5 million metric tons (MMT) of wheat worth USD 870 million (triennium average ending 2016, Table 1).

The Bangladesh Agricultural Research Council (BARC) categorizes land areas as very suitable (> 80% of the Maximum Attainable Yield - MAY), suitable (60–80% MAY), moderately (40–60% MAY) and marginally suitable (20–40% MAY) and not suitable (< 20% MAY) for the major crops (BARC, 2017). It shows that in Bangladesh, nearly half of the crop area is (very) suitable for wheat cultivation (Table 2), and geographically concentrated in the north-west of the country (Fig. 2).

4.2. Boro rice

Rice is the major staple crop of Bangladesh and is cultivated year-round across the country. Nearly 75% of the total 7.93 million ha of total cropland[2] (BBS, 2018) is solely allocated to rice production. There are three rice seasons: *aus* (rain-fed summer rice), *aman* (mostly rain-fed, wet season rice) and *boro* (mostly irrigated dry winter (*Rabi*) season). The *boro* rice is the most productive and market-oriented in Bangladesh (Hossain and da Silva, 2013). *Boro* rice is also the main winter crop in Bangladesh, cultivated from mid-November to June (Table 1). More than 63% of the total crop area of Bangladesh is (very) suitable for *boro* rice cultivation (Table 2). In 2016-17, 11.0 million ha of land was under all types of rice crop, of which the land under *boro* rice was on 4.5 million ha (BBS, 2018). In the same year, the total rice production was 33.8 million tons, of which, 53% (18.0 million tons) was *boro* rice. The average production of *boro* rice was 3.96 million metric ton worth of USD 3.5 billion (TE 2016-17, Table 1).

Among all three rice seasons in Bangladesh, the *boro* rice season is dominated by modern high-yielding (HYV) rice cultivars In 1971-72, the national average rate of the adoption of HYV rice was less than 6%; but more than 37% in the *boro* season (BRRI, 2017). In 2015-16, the national average rate of adoption of HYV rice exceeded 85% (across all three rice seasons); and even was 98.6% in the *boro* season (BRRI, 2017). The remarkable achievement of Bangladesh in ensuring rice production self-sufficiency is mainly attributed to the rapid adoption and expansion of HYV in the *boro* rice season (Dorosh et al., 2000; Hossain, 2009; Rahman and Parvin, 2009; Ahmed et al., 2000; Mishra et al., 2015).

Although Bangladesh is highly successful in achieving self-sufficiency in rice production, intensive irrigated *boro* rice's water needs are a major concern and its cultivation associated with negative impacts on the agro-ecology and environment of Bangladesh (Alauddin and Quiggin, 2008). The per hectare irrigation costs for *boro* rice cultivation are estimated at USD178, whereas it is USD76 for wheat and USD109 for maize (Lagos and Hossain, 2016, Table 3). Consequently, the overall production costs of *boro* rice are relatively high (USD 1,319 /ha) compared to wheat (USD 663/ha). (Lagos and Hossain, 2016). Due to the heavy extraction of groundwater mainly for irrigating *boro* rice, the groundwater levels in Bangladesh have been reportedly declining between 0.01-0.05 m yearly (Shamsudduha et al., 2009; Dey et al., 2013). Over-extraction of groundwater for *boro* rice irrigation is now considered a policy failure (Alauddin and Quiggin, 2008).

Intensively irrigated *boro* rice yields averaged nearly 4 tons/ha, but based on relatively high production costs, compared to the other winter crops (Table 3), the unit returns to *boro* rice do not look favorable compared to the returns of wheat in the wheat growing districts (Table 4). This is under the current scenario and prices (*ceteris paribus*). Assuming a complete replacement of wheat area in entire Bangladesh (432 thousand ha) by *boro* rice with a national average yield of 3.8 t ha^{-1}, the simulation exercise shows that, the total *boro* rice production would increase 1,727 thousand metric tons; but given lower gross margins of *boro* rice compared to wheat, the substitution would imply a

[2] Although the actual cropland in Bangladesh is 7.95 million ha, including double and triple cropping land, currently, the net cropland area in Bangladesh is 15.4 million ha (BBS, 2018).

Table 2
Crop suitability classification and district-level categorization for selected crops, Bangladesh.
Sources: [2]BBS (2018), [1]BARC (2017).

Crop name	Area million ha (%) by land suitability[1] class			Top 3 districts with		
	(Very) suitable	Moderate –marginal	Not suitable	highest (very) suitable crop land (ha)[1]	largest land (ha) allocated in 2016-17[2]	highest average yield (ton/ ha) in 2016-17[2]
Wheat	4.84 (49.4%)	2.42 (24.7%)	2.53 (25.9%)	Mymenshing (242,260), Dinajpur (231,342), Rangpur (187,868)	Takhurgaon (67,205), Pabna(33,012), Chapai Nawabganj (30,129)	Kushtia (3.81) Meherpur (3.55) Panchagarh (3.38)
Boro rice	6.20 (63.3%)	2.43 (24.8%)	1.17 (11.9%)	Mymenshing (329,226), Sunamganj (305,146) Tangail (249,455)	Mymenshing (232,181), Naogaon (178,646), Bogura (170,454)	Manikganj (4.60) Natore (4.59), Dhaka (4.55)
Maize	4.37 (44.5%)	2.39 (24.3%)	3.05 (31.1%)	Mymenshing (232,780 ha), Dinajpur (229,888) Naogaon (201,044)	Dinajpur (67,835 ha), Chuadanga (49,242 ha) Thakurgaon (36,930 ha)	Rajbari (13.5), Meherpur (10.9) Jamalpur (10.1)
Lentils	3.89 (39.6%)	1.74 (17.8%)	4.18 (42.7%)	Mymenshing (247,265), Jashore (153,878) Naogaon (210,912)	Magura (17,569 ha) Natore (15,309 ha), Rajshahi (14,448 ha)	Manikganj (2.42) Gaibandha (1.85) Chapai Nawabganj (1.75)
Gram (chick pea)	Same as lentils			Same as lentils	Rajshahi (1627), Chapai Nawabganj (773) Madaripur (570)	Pabna (1.53) Mymensingh (1.53) Bhola (1.43)
Onions	3.31 (33.8%)	4.12 (42%)	2.34 (24.2%)	Mymenshing (243,143), Jashore (152,972) Barishal (139,939)	Pabna (42,458) Faridpur (33,172) Rajbari (26,158)	Meherupur (25.0), Rajshahi (14.4) Chuadanga (13.8)
Garlic	Same as onion			Same as onion	Natore (20,968) Pabna (9604) Rajbari (5493)	Meherpur (8.6) Maulvibazar (7.7) Magura (7.6)
Potatoes	4.43 (45.1%)	3.03 (30.1%)	2.35 (24%)	Mymenshing (255,440), Dinajpur (233,681) Tangail (108,822)	Bogura (64,610), Rangpur (54,874) Dinajpur (48,861)	Munshiganj (32.7) Narayanganj (28.61) Bhola (26.7)

net negative expected return worth USD 252 million (Table 4).

Under scenario 2, assuming the replacement of current wheat area in 42 blast vulnerable and affected districts (261.4 thousand ha wheat area), and under scenario 3; only in 10 wheat blast affected districts (142 thousand ha wheat area) by *boro* rice also would imply net loss worth of USD 147 million (Table 5) and USD 84 million (Table 6), respectively. In addition, the replacement of the current wheat crop with *boro* rice could aggravate the negative consequences on the underground water reservoir and the overall ecology. *Boro* rice cultivation is also more labor-intensive than wheat (Table 3), which may aggravate seasonal labor shortages due to the rapid migration of the rural labor force to the urban areas of Bangladesh (Mottaleb et al., 2016). Overall, replacing wheat in any sampled region of Bangladesh with *boro* rice to implement a 'wheat-holiday' policy may not be a feasible option.

4.3. Maize

With the highest yield potential in South Asia (Timsina et al., 2010), maize is the third-most important cereal in Bangladesh. The dry-season winter *(Rabi)* maize in Bangladesh is cultivated from mid-October to May (BBS, 2018), and the summer maize (*Kharif)* is cultivated from March to June (Karim, 1992). In Bangladesh, nearly 45% of the total crop area is (very) suitable for maize cultivation (Table 3).

Mainly due to the growing demand from the poultry, livestock and aquaculture sectors, maize demand and production in Bangladesh have increased drastically since the 1990s (Mottaleb et al., 2018c). In 1983-84, 4,000 ha of land in Bangladesh were allocated to maize, and the total production was 3,000 metric tons. In 2016-17, 389,713 ha of land were allocated to maize, and the total production was more than 3.0 MMT (BBS, 2018). The triennium average value of maize production was USD 559 million (Table 1). Still, to meet the increasing demand for maize, Bangladesh relies heavily on imports. From 2014-16, on average, Bangladesh imported 652,000 metric tons of maize worth USD 153 million (Table1).

Assuming a complete replacement of wheat area by maize, the simulation exercise shows that, with a national-level maize yield (5.2 t ha^{-1}), total additional maize production will be 2.81 million metric tons, resulting in a positive net margin of USD 203 million (Table 4). Similarly, assuming a replacement of wheat area of 42 blast vulnerable and affected districts and only in 10 blast affected districts by maize, the simulation exercise shows a positive net margin of USD 105 million (Table 5) and USD 75 million (Table 6), respectively. Still, MoT reportedly survives in maize undermining its effectiveness for wheat blast eradication (Urashima et al., 2005). Therefore, even though maize can be an economically feasible alternative crop to wheat, suggesting maize as an alternative to wheat to combat wheat blast may not be a viable option in Bangladesh.

4.4. Lentils and gram

Among all types of pulses, lentils (*masur*) and gram (chickpeas) are considered important minor crops in Bangladesh, which are grown from mid-October to early March (BBS, 2016). In 2016-17, out of the total 389,700 hectares of land allocated to pulse cultivation in Bangladesh, nearly 42% was allocated to lentils and 1.5% to gram (BBS, 2018). The land suitability assessment of BARC (2017) indicates that lentils and gram are the same types of crops, for which less than 40% of the total crop area of Bangladesh is (very) suitable (Table 2).

Despite pulses such as lentils and gram being common food items in Bangladesh's cuisine and their increasing demand, the total land area allocated to these crops has been continuously declining in Bangladesh. For example, in 1986-87, 716,000 ha of land were under pulses, with a total production of 510,000 metric tons; whereas, in 2013-14 the area was reduced to 345,448 ha with a production of 320,443 metric tons (BBS, 2016). In the case of lentils and gram, on triennium average ending 2016-17, areas amounted to 151,500 and 6,400 ha (BBS, 2018) with a total production worth USD160 million and USD 4.3 million, respectively (Table 1). To meet the growing demand for lentils, gram and other pulses, Bangladesh heavily depends on imports. For example, from 2014-16, the triennium average shows that Bangladesh imported 207,600 MT of lentils and 233,200 MT of gram, worth USD175 million and USD 135 million, respectively (Table 1).

Assuming a complete replacement of wheat by lentils in entire Bangladesh, the simulation exercise shows that, with a national average

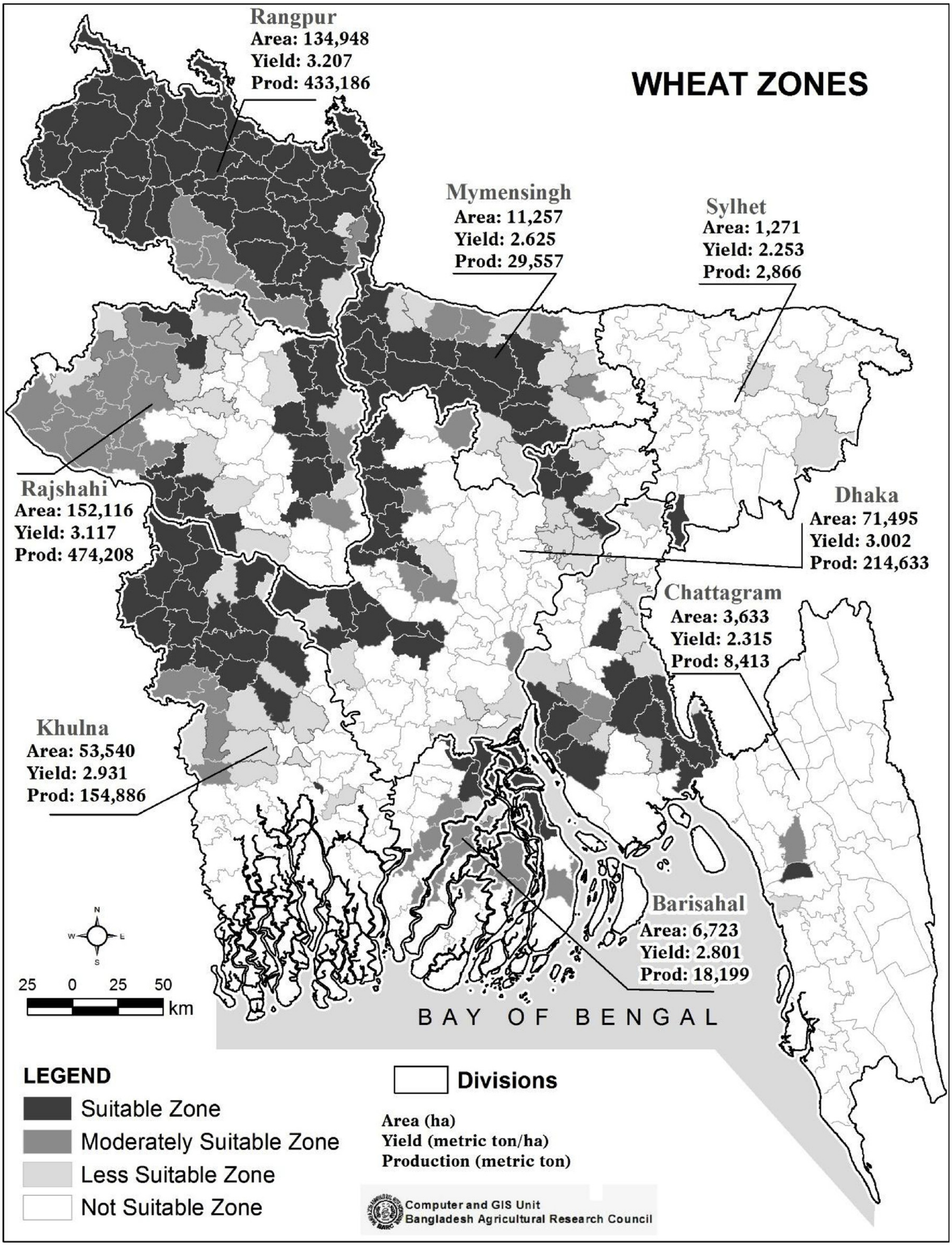

Fig. 2. Wheat suitability map and actual wheat area, production and yield by division in Bangladesh (triennium average ending 2016-17).
Source: BBS (2016, 2018); BARC (2017).

lentil yield (0.94 t ha^{-1}), total additional lentil production will be 446,200 metric tons for a positive net return of USD 77 million. However, presently the yearly total lentil consumption (import and domestic production) is 372,000 tons, so a replacement of wheat area by lentils in entire Bangladesh would make Bangladesh a potential net exporter of lentils. Alternatively, assuming replacement of wheat by lentils in 42 blast vulnerable and blast affected districts and only in 10 blast affected districts, the simulation exercise shows that, total additional lentil production will be 291 (Table 5) and 161 thousand metric tons (Table 6) for positive net returns of USD 70 million (Table 5) USD 38.3 million (Table 6), respectively. It indicates that lentil cultivation can be expanded in the suitable areas of blast affected and blast vulnerable districts of Bangladesh.

Assuming a complete replacement of wheat area by the gram, the simulation exercise shows that with a national-level gram yield (0.80 t ha^{-1}), total additional gram production will be 442,000 metric tons;

Table 3
Production costs (USD/ha) of the sampled crops in Bangladesh.
Sources: [1]Lagos and Hossain (2016), [2]Rahman and Hasan (2011); [3]Sabina et al., 2017; [4]BBS (2015a, 2015b); [5]Rahman et al., 2012; [6]Haque et al., 2013; [7]Sujan et al., 2017; [8] For lack of data assumed same as lentil.

Crop name	Total production cost	Irrigation cost	Labor cost
Wheat[1]	663	76	103.7[2]
Boro rice[1]	1319	178	495.6[3]
Maize[4]	756.0	109.1	207.4
Lentils[5] & Gram[8]	644.5		171.1
Onions[4]	1695.8	115.8	1104.1
Garlic[6]	948.3	98.0	292.4
Potatoes[7]	2954.6	43.5	733.4

tons (BBS, 2016), but in 2016-17, it was 412,000 ha with a total production of 2,674 thousand metric tons (BBS, 2018). In 2016-17, onions and garlic occupied 177,600 and 61,400 ha for a total value of USD 787 million and USD 329 million, respectively (Table 1). Despite the increased land allocation and production of onions and garlic, Bangladesh depends on imports to meet growing demands (Table 1).

Assuming a complete replacement of the current wheat area by onions, the simulation exercise shows that, with a national-level onion yield (6.98 t ha^{-1}), total additional onion production will be 3.92 million metric tons resulting in a positive net return net of USD 931 million (Table 4). Onion cultivation is extremely input intensive and requires relatively high labor, fertilizer and seed costs compared to the other sampled crop (Table 3). Also, the total onion consumption (domestic production and imports) is 2.2 million tons (Table 1), so a replacement of wheat in entire Bangladesh by onions would make Bangladesh a potential net exporter of onions. Assuming the replacement of the current wheat area in 42 blast vulnerable and affected districts and only in 10 blast affected districts by onions, the simulation exercise shows the expected positive net margin of USD 726 million (Table 5) and USD 517 million (Table 6) respectively. It indicates that onion cultivation can be expanded in the suitable areas at least in the blast affected and blast vulnerable districts of Bangladesh.

Table 4
Alternative scenarios assuming replacing wheat area (432,320 thousand ha) by the sampled alternative crops in entire Bangladesh (scenario 1).
Sources: Authors calculation.

Crop	Actual/potential production ('000, tons)	Gross Return (GR_c million USD)	Expected total Production Cost (PC_c, million USD)	Gross Margin (GM_c = GR_c - PC_c, million USD)	Expected Net Margin (difference in GM relative to wheat) (ENM_c = GM_c,- GM_w, USD/ha)
Wheat	1335.9	365.1	286.6	78.5	–
Boro rice	1727.3	397.1	570.2	−173.1	−251.6
Maize	2810.3	608.7	326.8	281.9	203.4
Lentils	446.2	434.2	278.6	155.6	77.1
Gram	442.0	291.8	278.6	13.2	−65.2
Onions	3917.8	1742.7	733.1	1009.5	931.1
Garlic	2523.4	2160.6	41.0	1750.1	1672.1
Potatoes	7914.2	1286.1	1277.3	8.7	−69.7

Notes: GR_c = gross return, PC_c = production cost, GM_c = gross margin, ENM_c = Expected net margin (net of wheat).

but given already unattractive per-hectare returns, the substitution would yield a negative net margin worth USD 65 million (Table 4). Simulation exercise also shows that a replacement of wheat area by the gram in blast vulnerable and affected districts and separately in 10 blast affected districts would yield losses of USD 17 million (Table 5) and USD 7 million (Table 6), respectively. Thus, gram does not seem a feasible alternative crop.

4.5. Onions and garlic

Onions and garlic are two major crops in the spices and condiments crop group of Bangladesh. In Bangladesh, onions are cultivated from October to mid-June and garlic is cultivated from mid-October to mid-March. Nearly 34% of the total crop area is (very) suitable (Table 2). Being widely used in daily food preparation, consumption, land allocation and the production of onions and garlic have been increasing rapidly over the years. For example, the total land allocation and the domestic production of spices and condiments (including onions and garlic) in 1988-89 were 143,000 ha and production was 295,000 metric

Similar to onions, assuming a complete replacement of wheat by garlic, the simulation exercise shows that with a national level yield (4.8 t ha^{-1}), total additional garlic production will be 2.52 million metric tons, yielding an additional USD 1.7 billion (Table 4). With a total garlic consumption of 440,000 tons, replacement of the current wheat area with garlic in entire Bangladesh would make Bangladesh, a potential net exporter. Assuming replacement of wheat area by garlic only in blast vulnerable and affected districts and separately in 10 blast vulnerable districts will yield a net gain of USD 1.1 billion (Table 5) and USD 573 million (Table 6), respectively. It indicates that suitability of

Table 5
Baseline sampled crop production information (triennium average ending 2016-17) in 42 blast vulnerable districts, and alternative scenarios assuming replacing wheat area by alternative crops (scenario 2).
Sources: Authors calculation, [1] BBS (2016, 2018).

Current scenario				Alternative scenarios replacing current wheat area by alternative crops				
Crop	Area (000, ha)[1]	Actual production ('000, tons)	Yield (metric ton/ha) [1]	Simulated production (000, ton)	GR_c, (million USD)	PC_c, (million USD)	GM_c (million USD)	ENM_c (million USD)
Wheat	261.4	799.4	2.46	Same as actual	218.5	173.3	45.2	–
Boro rice	2124.1	8295	3.79	1056.7	242.9	344.8	−101.8	−147.0
Maize	143.1	1067.6	4.90	1606.1	347.9	197.6	150.3	105.1
Lentils	148.1	160.8	0.95	291.2	283.4	168.5	115.0	69.8
Gram	4.10	5.92	0.79	270.8	178.8	168.5	10.4	−16.6
Onions	159.6	1631.4	7.0	2730.2	1214.4	443.3	771.1	725.9
Garlic	53.0	336.0	4.70	1592.6	1363.6	247.9	1115.7	1070.5
Potatoes	163.9	3732.3	17.1	4844.5	787.2	722.3	14.9	−30.2

Table 6
Base line crop production information (triennium average ending 2016-17) in 10-wheat blast affected districts and alternative scenarios assuming replacing wheat area by alternative crops (scenario 3).
Sources: Authors calculation, [1]BBS (2018).

Baseline information[1]				Alternative scenarios replacing current wheat area by alternative crops				
Crop	Area (000, ha)	Actual production ('000, tons)	Yield (metric ton/ha)	Simulated production (000, ton)	GR_c, (million USD)	PC_c, (million USD)	GM_c (million USD)	ENM_c (million USD)
Wheat	141.6	442.2	3.05	Same as actual	120.8	93.9	26.98	–
Boro rice	536.6	2104.6	3.87	566.0	130.1	186.7	−56.6	−83.6
Maize	85.6	719.8	6.73	963.3	208.6	107.0	101.6	74.6
Lentils	81.1	93.1	1.16	160.9	156.6	91.2	65.3	38.3
Gram	1.94	3.3	1.14	167.9	110.9	91.2	19.6	−7.4
Onions	105.0	1177.5	11.32	1763.7	784.5	240.1	544.4	517.4
Garlic	18.3	113.7	5.73	857.9	734.5	134.3	600.3	573.3
Potatoes	57.2	1280.7	20.9	2747.3	446.4	418.3	28.2	1.17

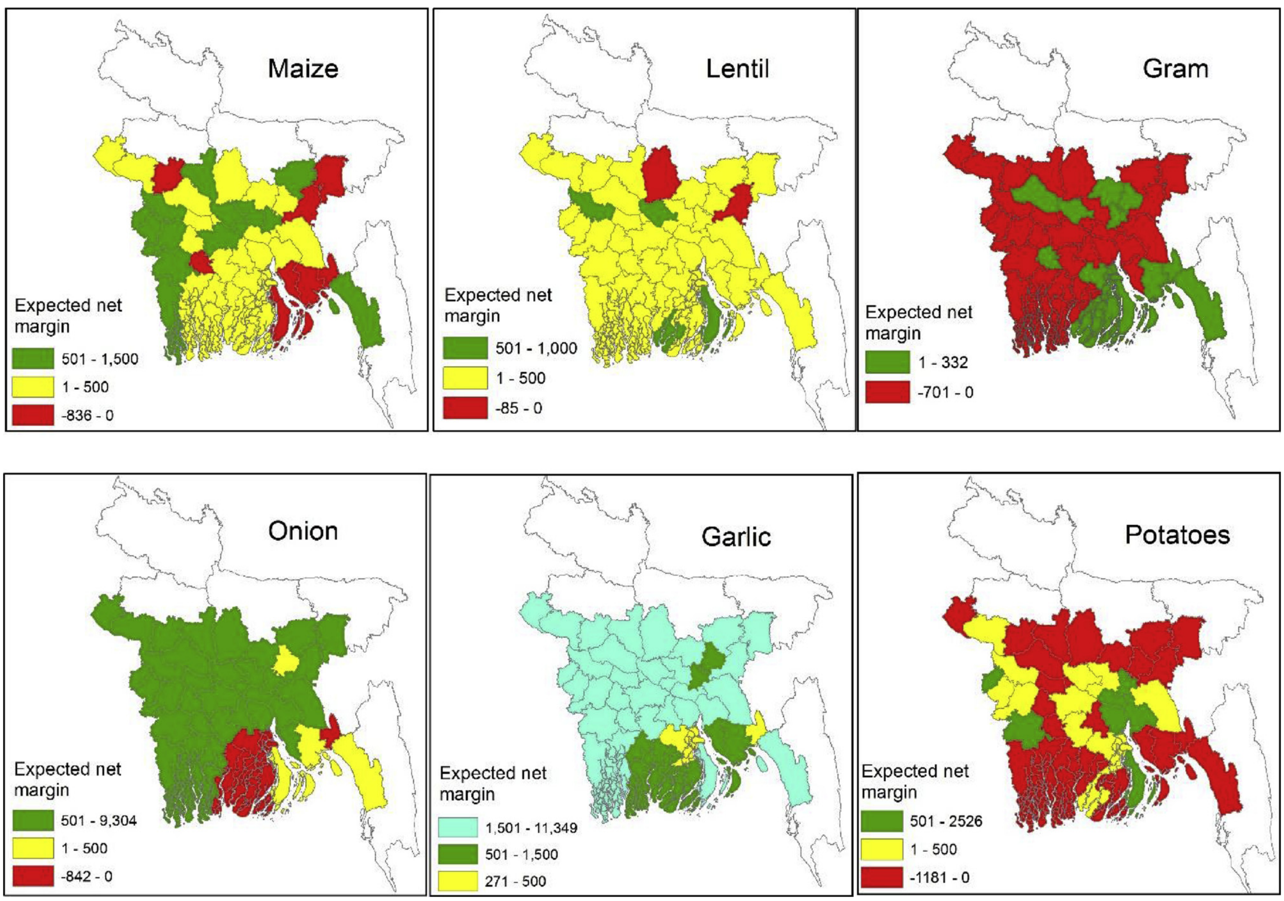

Fig. 3. Expected net margin (USD/ha) of the alternative crops to wheat in 42 blast vulnerable districts.
Source: Authors' calculation.

garlic as an alternative crop to wheat.

4.6. Potatoes

Potatoes are one of the major competing crops with wheat in Bangladesh; they are cultivated during the winter season from mid-September to March (BBS, 2018). With an average yield 16.7 t ha^{-1} (Table 1), Bangladesh is the seventh-largest potato producer in the world (FAO, 2017b). Currently, Bangladesh exports potatoes to Brunei, Malaysia, Nepal, Singapore, Sri Lanka, and Oman. In the 2014-15 fiscal year, Bangladesh exported USD 19.4 million worth of potatoes, but recently potato exports plunged due to export restrictions by Russia (Wardad, 2016). In the 2014-15- 2016-17 crop season, on triennium average of 9.6 million metric tons of potatoes were produced from 482,100 ha of land worth USD 1.56 billion (Table 1). In Bangladesh, more than 45% of the total crop area is (very) suitable for potato cultivation (Table 2).

Assuming a complete replacement of wheat by potatoes, the simulation exercise shows that, with a national-level potato yield (16.7 t ha^{-1}), total additional potato production will be 7.91 million metric tons and a negative net margin of USD 70 million (Table 4). Alternatively, assuming replacement of wheat by potatoes in 42 blast vulnerable and affected districts and only in 10 blast affected districts, the simulation exercise shows a negative net margin of USD 30 million (Table 5), but the positive net margin of USD 1.17 million (Table 6), respectively. Potato cultivation is highly laborious, and fertilizer- and

Table 7
Suggesting economically feasible alternative crops to wheat in the sampled 42 blast vulnerable districts considering district level production heterogeneity.
Source: Authors' calculation.

District/crop	Maize	Lentil	Gram	Onion	Garlic	Potatoes
Bagerhat	Y	N	N	Y	Y	N
Barguna	Y	Y2	Y3	N	Y	Y
Barishal	Y	Y	Y	N	Y	Y
Bhola	N	Y3	Y1	Y	Y	Y
Brahmanbaria	N	N	N	Y	Y	N
Chandpur	Y	Y	N	Y	Y	Y
Chattogram	Y	Y	Y	Y	Y	N
Chuadanga	Y3	Y	N	Y2	Y	Y
Cumilla	Y	Y	N	Y	Y	Y
Dhaka	Y	Y	N	Y	Y	Y
Faridpur	Y2	Y	N	Y	Y	Y
Feni	N	Y	Y	N	Y	N
Gazipur	Y	Y	Y	Y	Y	N
Gopalganj	Y	Y	N	Y	Y	Y
Hobiganj	N	Y	N	Y	Y	N
Jashore	Y	Y	N	Y	Y	Y
Jhalokati	Y	Y	N	N	Y	N
Jhenaidah	Y	Y	N	Y	Y	Y
Khulna	Y	Y	N	Y	Y	N
Kishoreganj	Y	Y	N	Y	Y	N
Kushtia	Y	Y	N	Y	Y	Y
Laksmipur	N	Y	N	Y	Y	N
Madaripur	Y	Y	N	Y	Y	N
Magura	Y	Y	N	Y	Y3	N
Manikganj	Y	Y1	Y	Y	Y	Y
Meherpur	Y1	Y	N	Y1	Y2	Y
Munsiganj	Y	Y	N	Y	Y	Y1
Narail	N	Y	Y	Y	Y	N
Narayanganj	Y	Y	Y2	Y	Y	Y2
Narsingdi	Y	Y	Y	Y	Y	N
Natore	N	Y	N	Y	Y	N
Chapai Nawabganj	Y	Y	N	Y	Y	N
Noakhali	N	Y	Y	Y	Y	N
Pabna	Y	Y	Y	Y	Y	N
Patuakhali	Y	Y	Y	N	Y	N
Perojpur	Y	Y	N	N	Y	N
Rajbari	Y	Y	N	Y	Y	N
Rajshahi	Y	Y	N	Y3	Y	Y
Satkhira	Y	Y	N	Y	Y	N
Shariatpur	Y	Y	N	Y	Y	Y3
Sirajganj	Y	Y	N	Y	Y	N
Tangail	Y	N	N	Y	Y1	N
No. of districts with positive expected net margin (net of wheat)	34	39	13	36	42	18

Notes: Y indicates the crop is an economically feasible alternative to wheat, N indicates it is not.Y1, Y2 and Y3 indicates that the crop is economically feasible and can generate the highest, second highest and the third highest positive expected net margin in the sampled district.

seed-intensive in Bangladesh, with the highest production costs among the considered crops (Table 3). Bangladesh is already a net exporter of potatoes, so the substitution for wheat implies the need for new markets for potato export. However, potato cultivation can be suggested in currently blast-affected districts, as a net return from replacing wheat area by potato is positive (Table 6).

4.7. District level heterogeneity

Tables 4–6 present the overall benefits of the sampled crops relative to wheat at the aggregated level. Fig. 3 considers the district-specific heterogeneity in suggesting a specific crop in a particular district based on district level gross margin of a crop in USD per hectare – which is summarized in Table 7. Table 7 shows that based on positive expected net margin (USD/ha) maize can be suggested as an alternative crop to wheat in 34 districts; lentil in 39 districts; onion in 36 districts; and garlic in all 42 blast vulnerable districts (Table 7). Interestingly gram and potatoes, which are economically infeasible alternatives at the aggregate level (Table 4–5), can be suggested at least in 13 and 18 districts, respectively (Table 7).

5. Conclusion and policy implications

Bangladesh is a relatively small wheat producer already heavily reliant on wheat imports. For Bangladesh, a 'wheat holiday', foregoing domestic wheat production to combat wheat blast, could be potentially possible as it 'only' allocates 432,300 ha land to wheat and domestically produces 32% of its total wheat demand. In fact, the government of Bangladesh is already discouraging farmers from growing wheat in the wheat-blast-affected districts. Not growing wheat, however, seems outright near impossible for bigger traditional wheat producers and consumers, such as India and Pakistan, where wheat is a major staple and a substantially large number of farmers depend on wheat cultivation for their food and livelihood.

Still, to realistically implement a potential 'wheat holiday' in any wheat-producing country, it is imperative to suggest economically viable alternative crops to wheat. This study examined the gross and net margins of alternative crops firstly in entire Bangladesh, secondly in 42 blast vulnerable districts and finally in 10 initially wheat blast affected districts, applying a simple *ex-ante* economic estimation framework. At face value, cultivation of onions, garlic, maize and lentils instead of wheat could be profitable, whereas *boro* rice, gram, and potato were not due to their negative net margins in the replacement area. Replacing with *boro* rice is also ecologically not feasible, due to intensive irrigation requirement. We also have suggested district level alternative crops, in which we have shown that a few crops such as gram may not be a feasible alternative for entire Bangladesh, but can be a feasible alternative to wheat in some specific districts. On the other hand, MoT can reportedly survive on maize (Urashima et al., 2005), so although an economically feasible alternative to wheat, caution must be taken in promoting maize if wheat blast control is the main driver.

Caution also must be taken when promoting the non-cereal crops due to the potential implications for making Bangladesh a net exporter (or further increasing exports for commodities such as potatoes) and the associated investments needed in inter alia value chains (including cold storage), credit facilities, and market search costs. For simplicity, the study assumes complete wheat substitution by a specific alternate crop in each scenario, but in reality, combinations may be more realistic and profitable. Furthermore, the simple model assumes constant prices in Bangladesh's open agricultural economy (with agricultural imports and exports) – which may need reconsideration if the substitution causes major market shifts in supply and demand for specific commodities.

A potential 'wheat holiday' would increase import reliance in the face of rapidly increasing per capita wheat consumption in Bangladesh linked to rapid increases in income, demographic change and urbanization. Considering the overall food security and volatile commodity prices in the international markets, the implementation of a potential 'wheat holiday' and complete dependence on wheat imports may not be an attractive nor politically feasible option to combat wheat blast in Bangladesh. Furthermore, the implementation of a national 'wheat holiday' would be logistically challenging in the current setting. The wheat-blast host-pathogen system also affects the feasibility of a potential 'wheat holiday.'

The present study thereby strongly suggests the national government and international stakeholders to adequately and urgently fund and research potentially viable alternatives to combat wheat blast in South Asia. This includes a need to look into the disease epidemiology and forecasting and the development and dissemination of new wheat-blast-tolerant/resistant varieties and complementary management practices in the South Asia setting. In the short run, reliance on the application of effective generic fungicides and seed treatment with fungicides is needed to combat wheat blast in South Asia and calls for fungicides being made widely and easily available to farmers at affordable prices. The provision of an early warning system and adequate information on disease management must be ensured to help farmers to effectively combat and minimize the consequences of the wheat blast in South Asia. In this interim period, the government of Bangladesh may need to rely on various measures, including potential implementation of a 'wheat holiday' at least in the severely blast-affected districts and encouraging farmers to cultivate lentils, onions and garlic. However, for a long-term structural solution, investments are needed in wheat-blast-related research and the development and dissemination of blast-resistant wheat varieties and complementary management practices in Bangladesh and South Asia. Promisingly, a blast resistant (and zinc-enriched) wheat variety *BARI Gom 33* has recently been released (October 2017) by the Bangladesh Agricultural Research Institute (BARI) with support from the International Maize and Wheat Improvement Center (CIMMYT). However, it will take at least three to five years before such a variety will be widely available to farmers throughout Bangladesh, given seed scaling challenges of a new introduction. This study strongly urges for international financial and technical support to speed up the seed multiplication and dissemination process. Finally, our methods could be replicated elsewhere as relevant, for instance in the case of other geographies and/or other diseases requiring a crop holiday. A case in point is West Bengal, India, where climate and agronomic practices are similar to Bangladesh, particularly in its border districts, and thereby particularly vulnerable to wheat blast. The West Bengal state government has already banned wheat cultivation in two districts and border areas, and there is thus a similar need to help identify profitable alternatives supported by empirically grounded studies.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

This study was supported by the CGIAR research program on wheat agri-food systems (CRP WHEAT) and the Australian Center for International Agriculture Research (ACIAR). The support of Mr. Victor Manuel HERNÁNDEZ RODRÍGUEZ and Mr. Alfredo GONZÁLEZ RAMOS, GIS Unit, SEP, CIMMYT, Mexico in generating maps, is greatly acknowledged. The views expressed here are those of authors and do not necessarily reflect the views of the funders or associated institutions. The usual disclaimer applies.

References

Ahmed, R., Haggblade, S., Chowdhury, T. (Eds.), 2000. Out of the Shadow of Famine: Evolving Food Markets and Food Policy in Bangladesh. The Johns Hopkins University Press, Baltimore: (Md., U.S.A.) and London.

Alauddin, M., Quiggin, J., 2008. Agricultural intensification, irrigation and the environment in South Asia: issues and policy options. Ecol. Econ. 65 (1), 111–124.

BARC (Bangladesh Agricultural Research Council), 2017. Land Suitability Assessment and Crop Zoning of Bangladesh. Dhaka: Ministry of Agriculture. Accessed 16, July 2017. http://cropzoning.barcapps.gov.bd/homes/downloads/1.

BBS (Bangladesh Bureau of Statistics), 2015a. *Report on Productivity Survey of Maize Crop 2014*. Dhaka: Productivity Assessment Survey of Different Agricultural Crops Programme, BBS, Statistics and Informatics Division (SID). Ministry of Planning.

BBS, 2011. Yearbook of Agricultural Statistics-2011. Dhaka: Statistics and Informatics Division, Bangladesh Bureau of Statistics. Ministry of Planning.

BBS, 2015b. *Report on Productivity Survey of Onion Crop 2014*. Dhaka: Productivity Assessment Survey of Different Agricultural Crops Programme, BBS, Statistics and Informatics Division (SID). Ministry of Planning.

BBS, 2016. Yearbook of Agricultural Statistics-2015. Dhaka: BBS, Statistics and Informatics Division. Ministry of Planning.

BBS, 2018. Yearbook of Agricultural Statistics-2017. 29th Series. Dhaka: Statistics and Informatics Division, Bangladesh Bureau of Statistics. Ministry of Planning.

BRRI (Bangladesh Rice Research Institute), 2017. Total Rice Area (000' ha) in Bangladesh. BRRI, Gazipur (Bangladesh) Accessed 16, July 2017. http://brri.portal.gov.bd/sites/default/files/files/brri.portal.gov.bd/page/b6531346_66a5_45e7_9cb0_d00c7c7009dc/Rice_Area_Bangladesh_29.01.2017.pdf.

Callaway, E., 2016. Devastating wheat fungus appears in Asia for the first time. Nature 532, 421–422.

Ceresini, P.C., Castroagudín, V.L., Rodrigues, F.Á., Rios, J.A., Eduardo A-, P.C., Moreira, S.I., Alves, E., Croll, D., Maciel, J.L., 2018. Wheat blast: past, present and future. Annu. Rev. Phytopathol. 56, 427–456.

CIMMYT (International Maize and Wheat Improvement Center), 2017. Semi-Annual Report, 2017. Cereal System Initiative for South Asia Phase III: Bangladesh and Nepal. Dhaka. CIMMYT, Bangladesh.

Cruz, C.D., Valent, B., 2017. Wheat blast disease: danger on the move. Trop. Plant Pathol. 42 (3), 1–13.

Dey, N.C., Bala, S.K., Islam, A.K.M.S., Rashid, M.A., Hossain, M., 2013. Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh. Dhaka: National Food Policy Capacity Strengthening Programme (NFPCSP) and BRAC, Bangladesh. Available from URL:. . [Accessed 22, March 2016]. http://www.nfpcsp.org/agridrupal/sites/default/files/ToR-2.pdf.

Dorosh, P., 2000. Foodgrain production and imports: toward self-sufficiency in rice? In: Ahmed, R., Haggblade, S., Chowdhury, T. (Eds.), Out of the Shadows of Famine: Evolving Food Markets and Food Policy in Bangladesh. John Hopkins University Press, Baltimore, Maryland, pp. 21–48.

Duveiller, E., Hodson, D., Sonder, K., Tiedermann, Av., 2011. An international perspective on wheat blast. Phytopathology 101, S220.

Duveiller, E., He, X., Singh, P.K., 2016. wheat blast: an emerging disease in South America potentially threatening wheat production. In: In: Bonjean, A.P., Angus, W.J., d van Ginkel, M. (Eds.), World Wheat Book: A History of Wheat Breeding 3. Lavoisier, Paris (France), pp. 1107–1122.

Erenstein, O., Thorpe, W., 2011. Livelihoods and agro-ecological gradients: a meso-level analysis in the Indo-Gangetic Plains, India. Agric. Syst. 104, 42–53.

FAO (Food and Agriculture Organization of the United Nations), 2017a. Food Balance Sheet: Rome (Italy): Food and Agriculture Organization of the United Nations. Available from URL:. [Accessed 22, November 2017]. http://www.fao.org/faostat/en/#data/FBS.

FAO, 2017b. Trade Data on Crop and Livestock Products. FAO, Rome (Italy) Accessed 20, October 2017. http://www.fao.org/faostat/en/#data/TP.

FAO. 2018. Trade data on crop and livestock products. Rome (Italy): FAO. Available from URL:http://www.fao.org/faostat/en/#data/TP, [accessed October 31, 2018].

Government of India (GoI), 2017. Pre-Rabi 2017 DAC & FW- ICAR Interface: Group *Recommendations*. New Delhi: Directorate of Extension, Department of Agriculture Co-Operation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare.

Haque, M.A., Miah, M.A.M., Hossain, M.S., Luna, A.N., Rahman, K.S., 2013. Profitability of garlic (*Allium sativum L.)* cultivation in some selected areas of Bangladesh. Bangladesh J. Agric. Res. 38 (4), 589–598.

Hossain, A., da Silva, J.T., 2013. Wheat and rice, the epicenter of food security in Bangladesh. Songklanakarin J. Sci. Technol 35 (3), 261–274.

Hossain, M., 2009. The Impact of Shallow Tubewells and *Boro* Rice on Food Security in Bangladesh. Available from URL:. International Food Policy Research Institute (IFPRI), Washington D.C . [Accessed 14, May 2015]. http://www.ifpri.org/sites/default/files/publications/ifpridp00917.pdf.

Igarashi, S., Utiamada, C.M., Igarashi, L.C., Kazuma, A.H., Lopes, R.S., 1986. *Pyricularia* emtrigo. 1. Ocorrência de Pyricularia sp. No estado do Parana. Fitopatol. Bras. 11, 351–352.

Islam, T., Croll, D., Gladieux, P., Soanes, D., Persoons, A., Bhattacharjee, P., Hossain, S., Gupta, D., Rahman, M.M., Mahboob, M.G., Cook, N., Salam, M., Bueno Sancho, V., Nunes Maciel, J., Nani, A., Castroagudin, V., Teodora de Assis Reges, J., Ceresini, P., Ravel, S., Kellner, R., Fournier, E., Tharreau, D., Lebrun, m.-h., McDonald, B., Stitt, T., Swan, D., Talbot, N., Saunders, D., Win, J., Kamoun, S., 2016. Emergence of wheat blast in Bangladesh was caused by a South American lineage of Magnaporthe oryzae. BMC Biol. 14 (84). https://doi.org/10.1186/s12915-016-0309-7. 1-1.

Karim, R., 1992. Studies on Maize in Bangladesh. International Food Policy Research Insitute (IFPRI), Washington D.C Accessed 20, October 2017. http://pdf.usaid.gov/pdf_docs/PNABS133.pdf.

Kohli, M.M., Mehta, Y.R., Guzman, E., De Viedma, L., Cubilla, L.E., 2011. Pyricularia blast - a threat to wheat cultivation. Czech J. Genet. Plant Breed. 47 (Special Issue), S130–S134.

Lagos, J.E., Hossain, T., 2016. *Bangladesh: Grain and Feed Annual.* GAIN ReportBG6005. Available from URL:. United States Department of Agriculture (USDA). Foreign Agricultural Service, Washington D.C , [Accessed 28, July 2017]. https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Dhaka_Bangladesh_3-31-2016.pdf.

Maciel, J.L.N., Ceresini, P.C., Castroagudin, V.L., Zala, M., Kema, G.H.J., McDonald, B.A., 2014. Population structure and pathotype diversity of the wheat blast pathogen Magnaporthe oryzae 25 years after its emergence in Brazil. Phytopathology 104 (1), 95–107.

Malaker, P.K., Barma, N.C.D., Tiwari, T.P., Collis, W.J., Duveiller, E., Singh, P.K., Joshi, A.K., Singh, R.P., Braun, H.-J., Peterson, G.L., Pedley, K.F., Farman, M.L., Valent, B., 2016. First report of wheat blast caused by *Magnaporthe oryzae* pathotype *triticum* in Bangladesh. Plant Dis. 100 (11), 2330.

Mason, N.M., Jayne, T.S., Shiferaw, B., 2015. Africa's rising demand for wheat: trends, drivers, and policy implications. Dev. Policy Rev. 33 (5), 581–613.

Mishra, A.K., Mottaleb, K.A., Khanal, A.R., Mohanty, S., 2015. Abiotic stress and its impact on production efficiency: the case of rice farming in Bangladesh. Agric. Ecosyst. Environ. 199 (1), 146–153.

Mottaleb, K.A., Krupnik, T.J., Erenstein, O., 2016. Factors associated with small-scale agricultural machinery adoption in Bangladesh: census findings. Rural Stud. 46, 155–168.

Mottaleb, K.A., Kruseman, G., Erenstein, O., 2018c. Determinants of maize cultivation in a land-scarce rice-based economy: the case of Bangladesh. J. Crop. Improv. 32 (4), 453–476.

Mottaleb, K.A., Rahut, D.B., Kruseman, G., Erenstein, O., 2018b. Wheat production and consumption dynamics in an Asian rice economy: the Bangladesh Case. Eur. J. Dev. Res. 30 (2), 252–275.

Mottaleb, K.A., Singh, P.K., Sonder, K., Kruseman, G., Tiwari, T.P., Barma, N.C.D., Malaker, P.K., Braun, H.-J., Erenstein, O., 2018a. Threats of wheat blast to South Asia's food security: an *ex-ante* analysis. PLoS One 13 e0197555.

Rahman, S., Hasan, M.K., 2011. Wheat in Bangladesh: profitability, production practices and environmental and managerial factors affecting yield. Chapter 11 In: Almeida, M.T. (Ed.), Wheat: Genetics, Crop and Food Production. Nova Science Publishers, New York, pp. 315–331.

Rahman, M.W., Parvin, L., 2009. Impact of irrigation on food security in Bangladesh for the past three decades. J. Waters Resour. Protection 3 (2009), 216–225.

Rahman, M.S., Hossain, M.A., Sarker, M.J.U., Bakr, M.A., 2012. Adoption and profitability of BARI lentil varieties in some selected areas of Bangladesh. Bangladesh J. Agric. Res. 37 (4), 593–606.

Reis, E., Blum, M.C., Forcelini, C., 1995. Sobrevivência de *Pyricularia oryzae*, associada as sementes de trigo. Summa Phytopathol. 21, 43–44.

Sabina, N.-E., Salim, R., Rahman, S., 2017. Eco-efficiency of high-yielding variety rice cultivation after accounting for on-farm environmental damage as an undesirable output: an empirical analysis from Bangladesh. Aust. J. Agric. Resour. Econ. 60, 1–18. https://doi.org/10.1111/1467-8489.12197.

Shamsudduha, M., Chandler, R.E., Taylor, R.G., Ahmed, K.M., 2009. Recent trends in groundwater levels in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta. Hydrol. Earth Syst. Sci. 13, 2373–2385.

Sujan, H.K., Islam, F., Kazal, M.H., Mondal, R.K., 2017. Profitability and resource use efficiency of potato cultivation in Mushiganj district of Bangladesh. Saarc J. Agric. 15 (2), 193–206.

Timsina, J., Jat, M.L., Majumdar, K., 2010. Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management. Plant Soil 335 (1), 65–82.

Urashima, A.S., Grosso, C., Stabili, A., Freitas, E., Silva, C., Netto, D., Franco, I., Bottan, J.M., 2009. Effect of *magnaporthe grisea* on seed germination, yield and quality of wheat. In: Wang, Guo-Liang, Valent, B. (Eds.), Advances in Genetics, Genomics and Control of Rice Blast Disease. Springer, Dordrecht (Netherlands), pp. 267–277.

Urashima, A.S., Leite, S.F., Galbieri, R., 2007. Efficiency of aerial dissemination o Pyricularia grisea. Summa Phytopathol. 33 (3), 275–279.

Urashima, A.S., Stabili, A., Galbieri, R., 2005. DNA fingerprinting and sexual characterization revealed two distinct populations of *Magnaporthe grisea* in wheat blast from Brazil. Czech J. Genet. Plant Breed. 41, 238–245.

USDA (United States Department of Agriculture), 2018. FAS Home/Market And Trade data/Production, Supply and Distribution Online. Available from URL:. USDA, Foreign Agricultural Service, Washington D.C . [Accessed 17, October 2018]. https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery.