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REVIEW PAPER

Wheat Production in Oman: Experiences, Challenges and Opportunities

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إنتاج القمح في عمان: الخبرات والتحديات والفرص

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ABSTRACT. Bread wheat (*Triticum aestivum* L.) is the leading staple and strategic food crop in the Sultanate of Oman; however, the national wheat production can meet less than 1% of the domestic requirements. The balance is met through imports from Australia, Canada, Russia, and Argentina. However, reliance on imported wheat alone may put Oman at risk in the event of wheat export bans. Therefore, wheat production needs to be enhanced to ensure national food security. Nonetheless, water deficits, salinity, prolonged droughts, unavailability of stress resilient genotypes, and heatwaves challenge this notion. In this review manuscript, the current status, constraints, and opportunities to improve wheat production in the Sultanate of Oman have been discussed. The major opportunities to improve the wheat production include crop improvement (i.e. development of short duration, high yielding, disease resistant and climate resilient varieties), efficient irrigation system, adoption of conservation agriculture to conserve the resources, strengthening system of certified seed distribution, seed enhancements, and development and dissemination of site-specific production technologies.

KEYWORDS: Grain yield, abiotic stresses, water efficient genotypes, seed enhancement

الملخص:قمح الخبز (*Triticum aestivum* L) هو المحصول الغذائي الرئيسي والاستراتيجي في سلطنة عمان. ومع ذلك ، فأن إنتاج القمح الوطني يلبي أقل من ١٪ من الأحتياج المحلي و يتم تحقيق هذه الأحتياجات من خلال الواردات من أستراليا وكندا وروسيا والأرجنتين. علما بأن الاعتماد على القمح المستورد وحده قد يعرض السلطنة للخطر في حالة حظر تصدير القمح. لذلك ، يحتاج إنتاج محصول القمح إلى التطوير لضمان الأمن الغذائي الوطني. ومع ذلك ، فإن عجز المياه ، والملوحة ، والجفاف لفترات طويلة ، وعدم توفر الأنماط الجينية المحلية من القمح المقاومة للإجهاد ، وموجات الحرارة تتحدى هذه الفكرة. وفي مخطوطة المراجعة هذه تمت مناقشة الوضع الحالي والقيود والفرص المتاحة لتطوير إنتاج القمح في سلطنة عمان حيث تضمنت الطرق الرئيسية لتحسين إنتاج القمح و المحاصيل (أي تطوير أصناف قصيرة الأجل وعالية الأنتاجية ومقاومة للأمراض ومقاومة للظروف المناخية)كما اشنملت على نظم ري وطرق زراعة فعالة للحفاظ على الموارد وتعزيز نظم توزيع البذور المحسنة المعتمد ونشر تقنيات الإنتاج الخاصة بالمواقع.

الكلمات المفتاحية: أنتاجية الحبوب ، الضغوط اللاأحيائية ، التراكيب الجينية ذات الكفاءة المائية ، تحسين البذور.

Introduction

Bread wheat (*Triticum aestivum* L.) is the leading staple and strategic food crop in the Sultanate of Oman. It is grown under irrigated conditions, however, in the Musandam region, rainfed wheat is also cultivated (MAF, 2019). The wheat is used for making Omani bread resembling thin papery sheets locally known as '*Khubz*' or '*Karam*' besides its use in '*Omani Halwa*' (a local popular sweet). The national wheat production can meet less than 1% of the domestic requirements. Historically, wheat grown in Oman had been sufficient to fulfill the domestic requirement. Therefore, there was no wheat import in the country from 1961 to 1980. After the 1980s, a continuous increase in the wheat import in Oman has been noted (Figure 1) to meet the domestic requirements.

Total arable land in Oman is about 2.2 M ha which is 7% of the total area of Oman (31.4 M ha) (MAF, 2010). However, the actual cropped area in the Sultanate is 62,000 ha, which is 2.8% of the total arable land and 0.2% of the total area of the country. Due to continuous efforts to achieve food security in the country, an increase of 7.9% in the cultivated land area was noted during the year 2018. During 2018-19, 3, 579 tons of wheat were produced from an area of 472.28 ha in the country (Figure 2). This area under wheat is spread in different parts of the country (Figure 3). During 2018-19, the Wilayat Ibri recorded the highest production of 293.8 tons, followed by 142.3 tons in the Wilayat Bahla, 99.2 tons in the Wilayat Dhank, 93.2 tons in the

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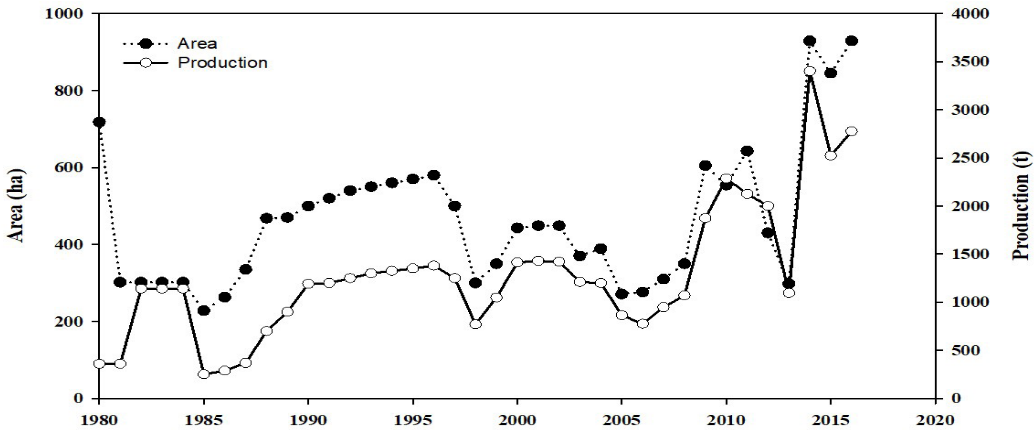

Figure 1. Area and production of wheat during last six decades in the Sultanate of Oman (Source: www.fao.org/faostat)

Wilayat Yanqul, and 55.1 tons in the Wilayat Nizwa. The low national food production dictates the increase in imports and a rise in prices. In addition to a decrease in area under wheat, the average wheat yield is also very low (Figure 2). The major reasons for low wheat yield in Oman include moisture deficit, high temperature, soil, and water salinity, growing of low yielding varieties and landraces, and unavailability of climate-resilient wheat genotypes. Moreover, policy-related bottlenecks as the non-existence of effective extension services to transfer site-specific production technologies, unavailability of skilled farm labour, lack of efficient water management strategies, and non-adoption of modern farm machinery also cause a decrease in wheat production and average yield. Furthermore, the area under wheat has been substituted with fodder and vegetable crops due to better returns.

In the current climatic conditions, there is potential to increase wheat production through the introduction of climate-resilient and high-yielding wheat genotypes, the application of an efficient irrigation system, and a site-specific suit of production technology. In this review, the history of wheat research and associated challenges are discussed. Furthermore, pragmatic options to enhance wheat productivity and production, and food security are proposed.

Brief History of Field Crop Research in Oman

There were two agricultural research stations earlier in the 1970s located at Sohar and Nizwa where the research on fruit, vegetable, field, and forage crops was initiated (MAF, 1970). In the year 1971, two more research stations were established at Rumais (Welayat Barka) and Wadi Quriyat (Welayat Bahla). A separate section of field crop research, with the headquarter at Wadi Quriyat and regional offices at Rumais and Salalah was established with a mandate of research on various aspects of cereal, grain legumes, oilseed and forage crops (MAF, 1971). At Rumais, experiments were conducted during 1972-73 and 1973-74 on a limited scale (MAF, 1973-74). From 1975-77, a detailed program of research on field crops was initiated at Rumais and Salalah with the appointment of the research staff at these locations (MAF, 1978). At Wadi Quriyat, the location was shifted in 1982-83 from the old farm to the present date farm location and research was initiated at Welayat Al-Kamil in the Sharqiya governorate (MAF, 1983). In 1990, all activities of field crops were shifted from Wadi Quriyat to Jimah (Welayat Bahla) (MAF 1991, 93). During 1973 to 1990, comprehensive experiments on crop improvement and management were conducted at Wadi Quriyat. During 1995-96, the activities were extended to other Agriculture Research Stations located at Sohar and Al-Kamil (MAF, 1995-96). The research materials for field and forage crops were received from 'The International Center for Agricultural Research in the Dry Areas' (ICARDA), Aleppo, Syria, 'The International Crops Research Institute for the Semi-Arid Tropics' (ICRISAT), Hyderabad, India, 'The International Institute of Tropical Agriculture (IITA)', Ibadan, Nigeria, 'The International Maize and Wheat Improvement Center (CIMMYT)', Mexico, 'The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD)', Syria, 'The International Center for Biosaline Agriculture (ICBA)', Dubai, United Arab Emirates, 'The International Atomic Energy Agency', Vienna, Austria, and from many private companies especially in case of vegetables and fruit crops besides forage crops like Rhodes grass and alfalfa (MAF, 1994, 2000).

Meanwhile, agricultural research activities at the establishment of the College of Agricultural and Marine Sciences at the Sultan Qaboos University were as part of an educational program or independent research programs under the projects by the staff and faculty through institutional, national and international funding on the problems faced by the farming community in the field, vegetable, fruits and forage crops (SQU, 2020).

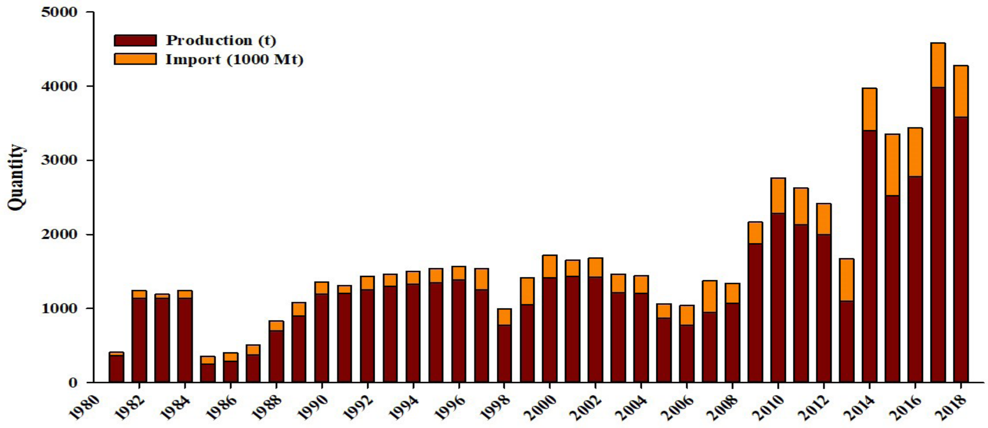

Figure 2. Wheat production, import, and total requirement of Sultanate during last six decades (Source: www.fao.org/faostat)

The research on field crops, in Oman, was focused on: (i) identification of high yielding genotypes under local conditions, (ii) development of the package of production practices for the field crops, (iii) research on emerging biotic and abiotic problems in field crops, (iv) identification of crop genotypes tolerant to drought, salinity, and heat stresses, and (v) dissemination of package of production practices for the cultivation of field crops (Akhtar and Nadaf, 2001).

The research on wheat was initiated in the 1970s with the start of experiments on field crops in Oman. The research activities were, in general, focused on identification and selection of suitable high yielding elite genotypes under Oman conditions, and optimization of crop husbandry practices including planting date, planting method, planting density, and plant nutrition, etc. (Akhtar and Nadaf, 2001). Subsequently, research orientation was tuned to address the problems faced

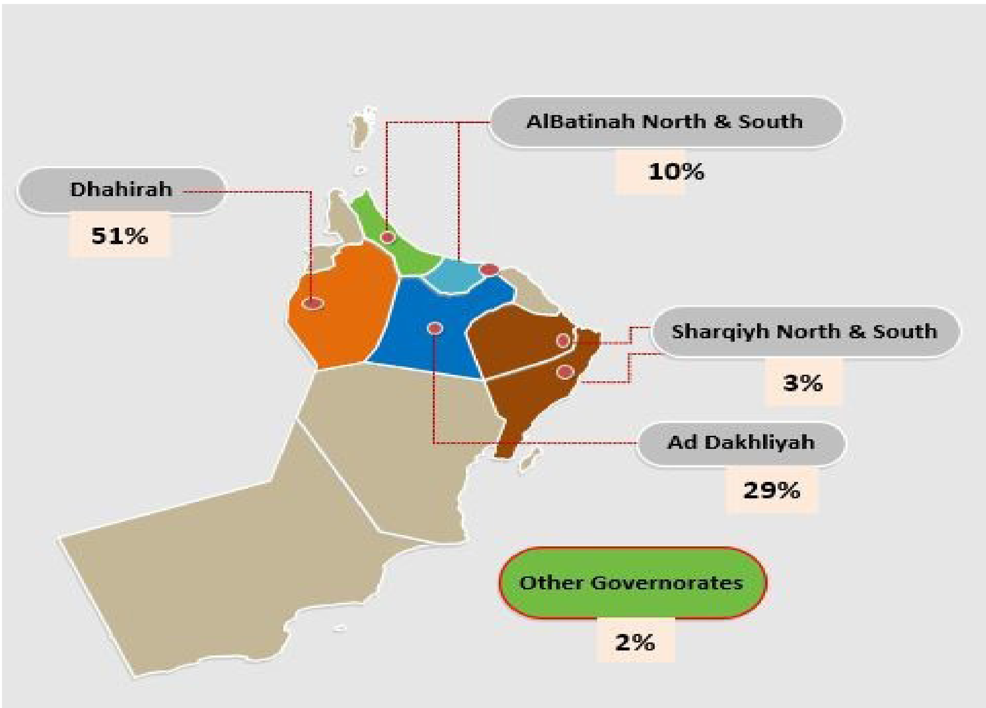

Figure 3. Major wheat production areas in the Sultanate of Oman

Table 1. Agronomic characters and disease reaction of improved varieties released for cultivation during 1970-2019

Sr. No.	Selection name	Source	Year of release	Days to heading	Days to maturity	Plant height (cm)	Grain yield (t/ha)	Reaction to leaf rust	Reaction to stem rust
1	WQS 151	ICARDA	85/86	65	120	80	3.10	1	1
2	WQS 160	ICARDA	85/86	75	122	75	3.20	2	1
3	WQS 302	ICARDA	96/97	65	120	65	4.00	0	0
4	WQS 305	ICARDA	93/94	68	120	85	4.01	1	0
5	WQS 308	MEXICO	92/93	75	120	85	3.67	1	0
6	Jimah 1*	CIMMYT	96/97	75	120	75	3.20	1	0
7	Jimah 2*	CIMMYT	96/97	75	121	85	3.95	1	0
8	Jimah 101	ICARDA/ CIMMYT	97/98	69	112	90	3.25	1	0
9	Jimah 102	ICARDA/ CIMMYT	97/98	62	108	86	3.30	1	0
10	Jimah 103	ICARDA/ CIMMYT	97/98	58	105	82	3.10	1	0
11	Jimah 107	ICARDA/ CIMMYT	98/99	73	114	84	4.9	-	-
12	JIMAH 110	ICARDA/ CIMMYT	98/99	77	121	84	4.4	-	-
13	JIMAH 125	ICARDA/ CIMMYT	99/2000	69	108	74	5.2	-	-
14	JIMAH 132	ICARDA/ CIMMYT	99/2000	69	108	81	4.0	-	-
15	WQS 226	ICARDA	2008/2009	60	108	103	4.0	1	1
16	WQS 225	Australia	2008/2009	69	113	88	4.9	0	0
17	WQS 227	ACSAD	2016/2017	78	118	85	4.5	-	-
18	Jibreen 1	MAF**	2018/2019	65-70	105-110	85-90	3.9	-	-
19	Nizwa 1	MAF**	2018/2019	65-70	105-110	85-90	3.5	-	-
20	Bahla 1	MAF**	2018/2019	65-70	105-110	85-90	3.6	-	-
21	Nejd 1	MAF**	2018/2019	65-70	105-110	85-90	4.1	-	-
Check	Cooley	Local	1970	71	140	110	1.96	3	2

* The names have been changed from Jimah to WQS with the same code number; - Not assessed. **National Crop Improvement Program through plant breeding

by the local growers such as breeding for high yielding and better-quality wheat genotypes tolerant to diseases.

Experiences

Introduction and Screening of High Yielding Genotypes Adapted to Local Conditions

During the 1970s, local landraces of wheat *viz*. Sarraya, Missani, Cooley, Hamira, Walidi, Shwaira and Greda were very popular among the growers (MAF, 1970). Two varieties *viz*. 31-1 and Gamanneya were introduced from Rajasthan, India, and Australia, respectively in the late 1960s. The variety 31-1 was resistant to rust whereas the variety Gamanneya was an awnless and tall statured with rust escape potential. As mentioned in the earlier section, Agricultural Research Station was established at Wadi Quriyat in the early 1970s, with a focus on wheat varietal improvement. The Research Station in collaboration with the ICADRA, the CIMMYT, and the Food and Agriculture Organization (FAO) started screening wheat varieties provided by these institutions. Later, wheat genotypes provided by ACSAD were evaluated for adaptability to local conditions. At the same time, some varieties were introduced from other countries e.g., Mexipak from Pakistan, Kalyansona, S. 227 and HD series from India, and Sannine from Lebanon. Out of these varieties, Mexipak, Kalayansona, and Sannine were released for commercial farming in Oman. The variety Kalyansona had a resemblance with Mexipak as both of these were developed from the breeding lines provided by CIMMYT (with one common parent) (MAF 1971, 1994-96). The varieties Mexipak and Sanine are still being grown in selected wheat-growing areas of the Sultanate (MAF 1971, 1994-96).

Two wheat varieties WQS 151 and WQS 160 (WQS after the name of Wadi Quriat Research Station), with the yield potential of 3.1 and 3.2 t ha-1, respectively, were released for general cultivation in 1985-86. Subsequently, WQS 161 was released in 1985-86, WQS 308 in 1992-93, WQS 305 in 1993-94, and WQS 302 in 1996-97 (MAF, 1992, 98). As the research station was shifted to its current location at Jimah, the varieties released later had the name of this station. For example, two promising varieties Jimah 1 and Jimah 2 were selected and released during 1998-99 for seed multiplication program for later distribution of seeds to wheat growers. Three promising varieties Jimah 101, Jimah 102 and Jimah 103 were also selected and released. Selection of wheat from institutional nurseries, observational nurseries, and regional trials of specific traits like salt and heat tolerance started in 1973-1974. The varieties and breeding lines were selected from the trials following the standard protocols. Subsequently, besides the ICARDA, the ACSAD started sending advanced breeding trials for mild winter for initial screening and evaluation and selection for release of high yielding lines for general cultivation (MAF, 2000; Table 1).

Crop Breeding for Improving Local Omani Bread Wheat Varieties

The Sultanate of Oman has an ancient history of cultivation of bread wheat because of its position at the eastern edge of the 'Arabian Peninsula' (Hammer et al., 2009; Filatenko et al., 2014). Wheat landraces constitute the prime genetic resource of cultivated wheat not only in Oman but also in several other Middle East and North African (MENA) countries (Al-Khanjari et al., 2005, 2007; Jaradat and Shahid, 2014). Indigenous landraces have the potential to use in crop improvement programs owing to a considerable morphological variation among and within landraces (Al-Maskri et al., 2003). Many wheat landraces have been collected from different parts of Oman during collecting missions in the 1980s and 1990s after Oman's inclusion in worldwide activities for the collection of plant genetic resources under the FAO program (Guarino, 1990). Although the wealth of the Omani landraces has been emphasized (Filatenko et al., 2008) on the morphological variation, tolerance to abiotic and biotic stresses, and quality traits, these aspects have been not significantly exploited (Jaradat and Shahid, 2014; Ahmad et al., 2014) as the information on the extent and pattern of genetic variation in these Omani wheat landraces is not available.

The Omani farmers prefer local wheat landraces, such as Cooley, Hamira, Sarraya, and Missani to cultivate but these local cultivars are low yielding, tall-statured, and susceptible to rust and smut diseases. Hence, the crop improvement program through conventional breeding was undertaken from 2001 to 2014 involving landraces to develop high yielding genotypes with the desired characteristics of local varieties such as better bread-making quality, tolerance to heat, and diseases (rust and smuts). The local varieties Sarraya, Missani, and Cooley (female parent) were crossed with exotic wheat varieties WQS-110, WQS-125, WQS-225 and WQS-302 (male parent). From the above crosses to get F2 seeds, seeds of the F1 generation were grown in the winter season of 2001-2002. During winter 2002-03, seeds of the F2 generation were grown and selection of F2 plants was based on plant height (short, medium, and tall), the number of tillers per plant (equal or higher than 7 tillers), time to heading and maturity (early, medium, and late), other relevant agronomic characters, and resistance against insect pests and diseases. In the F2 populations, pedigree method of breeding, and a higher selection intensity (0.05) was applied on a single plant basis (MAF, 2004-05). Subsequent final selections from 12 crosses led to the identification of 36 outstanding advanced high yielding F7 lines. These advance lines were grown during winter 2007-08 along with three standard local check varieties at Agriculture Research Station, Jimah (Al-Dakhiliyah governorate) and Agriculture Research Station, Al-Kamil & Al-Wafi (South Al-Sharqiya governorate). The results of the trials at both locations showed significant differences among the lines. Based on multi-location results the 10 promising lines were selected for early maturity, high yield, disease resistance, and baking quality. Further, these 10 lines were tested at on-farm trials in three different governorates (Al-Sharqiya, Al-Dakhiliyah, and Al-Batinah). Four lines belonging to the crosses Cooley × WQS125, Cooley × WQS 302, Sarraya × WQS302, and Sarraya × WQS 125 were released for commercial cultivation with the names Jibreen 1, Nizwa 1, Najd 1, and Bahla 1, respectively. The lines were selected for early maturity (at least 110 days), high yield (with at least 15% superiority), and better bread-making quality. The superiority percentage of these 4 varieties (Sarrya × WQ125, Sarrya × WQ302, Cooly × WQ125, and Cooly × WQ302) for grain yield was 52, 37, 32, and 28%, respectively over their local parents (Table 1; ARSJ, 2016). The variety Nejd 1 produced the highest grain yield (4.1 t ha^{-1}) followed by variety Jibreen 1(3.9 t ha^{-1}), Bahla 1 (3.6 t ha^{-1}), and Nizwa 1 (3.5 t ha^{-1}) (Table 1; ARSJ, 2016). These new varieties have merits of their earliness to save water for irrigation with all required bread-making quality traits of their local parents (Cooley and Sarraya) over, which they were evolved and developed. The seed of these four improved bread wheat varieties was multiplied during 2016 and the varieties were released for general cultivation in 2018-19 cropping season with the distribution of seeds among the farmers in the different agro-climatic regions. These four varieties were also registered with the 'International Union for the Protection of New Varieties of Plants' (UPOV) system with the information of Uniformity, Distinctness, and Stability (UDS) tests.

Crop Husbandry Practices

The experiments, involving different sets of wheat genotypes, were conducted on planting dates at Wadi Quriyat and Salalah from the 1970s to onwards. The 3rd week of November was found as the best time of planting at Wadi Quriyat, while the last week of October was ideal for wheat planting in the Salalah region. The varieties also differed for their responses to different planting dates. The late-maturing variety Cooley yielded more when sown in early November, whereas early maturing varieties like Mexipak yielded better when planted in late November (MAF, 1971-74). The experiments conducted at Jimah, during 1992-93 and 1993-94, showed that the wheat planting during mid-November yielded better compared to early or late plantings (MAF, 1992-94).

Different experiments on planting density were conducted at Al-Dakhliyah (Wadi Quriyat) and Salalah, during the 1970s and 1980s. The seed rate of 125 kg ha^{-1} at Wadi Quriyat, (for Mexipak) and Salalah (for Cooley) yielded the best. These studies conducted at Wadi Quriyat during 1988-89 indicated the highest yield of the variety Sannine was harvested using seed rates of 100 kg ha^{-1}, while at Jimah during 1991-92, 160 kg ha^{-1} was the best seed rate for the variety WQS 160. There was no difference between broadcast and line sowing in the experiments conducted during 1985 (MAF, 1985). However, the studies conducted during 1988-89, using the variety Sannine, showed that line sowing is better than the broadcast (both for grain and straw yield) (MAF, 1989). Within line sowing, the highest grain yields were recorded where wheat was planted in 20 cm rows whereas the highest straw yields were obtained from wheat planting in at 25 cm spaced rows (MAF, 1989).

Weeds were not an issue for wheat in the Al-Dakhiliyah governate because of a shift in cultivation (MAF, 1985). Therefore, controlling weeds, by chemical means or hand weeding did not show any yield benefit compared with weed check (MAF, 1987). The only experiment carried out in 1980 on cropping systems indicated that for line sowing wheat can be intercropped with chickpea, radish, and safflower, however, for broadcasting, it can only be mixed with chickpea (MAF, 1980).

The experiment conducted at Wadi Quriyat during the 1980s on the response of N-nitrogen, P-phosphorus, and K-potassium on both tall-statured and dwarf-statured wheat varieties indicated differential response for the N application. The tall-statured varieties like Cooley responded better to lower dose (66 kg N ha^{-1}) than the dwarf-statured varieties, whereas the dwarf-statured variety Mexipak yielded better at the higher dose (88 kg N ha-1). At Salalah, the fertilizer application at 80:60:40 kg ha^{-1} NPK produced the highest yield (2363 kg ha^{-1}) with no difference between methods of application. In another study conducted at Wadi Quriyat, the highest grain yield was obtained with 90 kg N ha^{-1} and irrigated at 7 days intervals (MAF, 1980). During 1988-89, the experiment was conducted at Wadi Quriyat to evaluate the response of seven wheat varieties to four nitrogenous fertilizer levels under sprinkler irrigation; it was concluded that N fertilization of 150 kg ha^{-1} in the split with four doses – (¼ at the time of sowing, ¼ at 10 days after sowing, ¼ at the heading stage and the remaining at milky grain stage) was the best strategy to harvest highest benefits (MAF, 1989). In another experiment, conducted at Wadi Quriyat, during 1988-89, the response of seven wheat varieties was evaluated against four P levels under sprinkler irrigation, and maximum yield was recorded at 90 kg P ha^{-1} (MAF, 1989).

Tolerance Against Drought and Salinity Stresses

Drought and salinity (both soil and water) are a serious problem of present-day agriculture in Oman and elsewhere too. Since the mid-1990s, several studies have been conducted on salinity tolerance in wheat. For example, in a study, the response of 12 known salt-tolerant wheat genotypes introduced from Egypt was evaluated to five levels of saline irrigation *viz*. control (2 dS $^{-1}$), 4, 8, 12, and 16 dS m^{-1} during winter 1996-97 and 1997-98. The years, genotypes, salinity levels, and the effects of their interactions were significant for most of the studied traits *viz*. days to flowering, leaf length, plant height, number of leaves, number of tillers plant^{-1}, spike length, grain yield plant^{-1}, tissue K^+, Na^+, Cl^- and K^+/Na^+ ratio. There was no significant difference in response of genotypes for most of the characters between control (2 dS m^{-1}) and 4 dS m^{-1} while the genotypes varied in their performance under higher salinity levels (Nadaf et al., 2001 a, b). In another study, six local wheat landraces/varieties *viz*. Sarraya, WQ110, Missani, Sannin, Cooley, and Humaira were screened for salinity during 2011-13. The preliminary results for the total grain weight of the cultivars under the different treatments showed that Missani, Sannin, Cooley, and Humaira were tolerant to 6 dS m^{-1} (MAF, 2012-13). In another study, based on water conservation 7 local landraces of wheat (both bread & durum wheat) were evaluated for stem structural and specific leaf features. The tested wheat landraces were ranked as S-24 > J-305 > Sarraya > Senain > Cooley > MH-97 > Missani>Hamira > Shwairaa based on shoot fresh and dry weights, and degree of tolerance to drought and salinity stresses. The succulence in leaf and stem, a high degree of sclerification, pubescence on the leaf surface, and low resistance to water conductance in vascular tissue contributed to the water conservation. A high proportion of chlorenchyma and intensive sclerification in stem structure, dense pubescence on the leaves, and well-developed bulliform cells were recorded in drought and salt tolerant cultivar S-24. In other Omani wheat landraces like Shwairaa and Hamira, these modified features were poorly developed, which were less tolerant to salinity and drought (Al-Maskri et al., 2014).

To improve crop growth in saline soils the excess salts need to be leached below the root-zone and should not be allowed to come up. In a field study conducted at Agriculture Research Station, Rumais, the effects of saline irrigation water with three levels *viz*. 3, 6, and 9 dS m^{-1} were evaluated based on yield and leaching.

With the increase in salinity of the irrigation water (and consequently soil), the corresponding decrease in the yield components and grain yield was noted. However, with 35% leaching application a significant increase in yield and yield components was recorded. Likewise, the leaching × saline irrigation water was significant for grain yield and yield components. Increases in grain and straw yield were associated with increases in the leaching to a certain limit. A leaching fraction of 35% was preferable if the salinity of irrigation water was less than 9 dS m^{-1}. The saline irrigation water could be used in combination with leaching fraction as an alternative and less expensive technique to irrigate crops like wheat, to improve the grain yield and the agricultural economy of salt-affected areas (MAF, 2002).

Use of Treated Wastewater for Wheat Production

In the arid regions, the irrigation of crops with reclaimed sewage water can contribute to the saving and conservation of water resources. Around the globe, many countries in the North Africa, Middle East, and Sub-Saharan Africa are facing serious water shortages. During 2010-11, different field studies were conducted to evaluate the yield response of other and wheat crops grown in rotation with reclaimed water in comparison to the ground and desalinated water. The growth, grain yield, and water productivity of wheat were improved with reclaimed irrigation water (Al-Khamisi et al., 2017). During the winter seasons of 2008-09 and 2009-10, a similar study was conducted at Agricultural Research Station, Rumais to evaluate the response of fresh and treated wastewater on the performance of 3 different wheat varieties WQS 110, WQS 302, and WQS 308. The maximum grain yield of 3.85 t ha^{-1} was recorded in variety WQS 302 irrigated with treated wastewater followed by WQS 110 (3.70 t ha^{-1}) and WQS 308 (3.46 t ha^{-1}). There was no difference in N contents in the genotypes except water treatments as plants irrigated with treated wastewater had more N content than freshwater treatment. However, there were no significant differences in fresh and treated waste water and between the varieties for the concentrations of different heavy metals (MAF, 2010-11).

Expansion of Wheat to Other Governorates

The traditional wheat-growing areas in Oman are the governorates of Al-Dakhiliyah and Al-Dhahirah. The yield potential of field crops depends on the genetic make-up of genotypes and the environmental conditions where they are grown (Ali et al., 2010). The adaptation of different wheat varieties in different governorates of Oman is generally related to temperature and humidity. Either of these factors influences the grain yield and grain quality. During the 1980s, the first experiment was conducted to evaluate the released varieties under very low temperature conditions of Jabel Akhdar (MAF, 1981-83). Two varieties of wheat *viz.* Sannine and Cooley were planted at Jabel Akhdar in early January and early March. Both varieties yielded well when planted in January producing 4.6 t ha^{-1} (Sannine) and 3.0 t ha^{-1} (Cooley) as compared to March planting (Sannine-2.25 t ha^{-1}; Cooley-1.0 t ha^{-1}) (MAF, 1984). Since mid-2000, the area under wheat expanded to Al-Batinah governorate under changed humid conditions due to climate change. The results of previous trials indicated that the grains of variety WQS 110 cultivated in the Al-Batinah governorate were smaller than the grains of the same variety planted in the Al-Dakhiliyah governorate possibility due to the weather variability. The five wheat varieties (*viz.* WQS 110 Interior, WQS 110 Batinah, WQS 101 Interior, WQS 308 Interior, and WQS 302 Interior) were planted during winter 2007-2008 at two locations (*viz.* Jimah, Al-Dakhiliyah, and Sohar, North AI-Batinah) to compare their responses for yield and grain quality. There were significant differences among the varieties and between the locations. The varieties WQS 110 (Interior) and WQS 110 (Batinah) produced the highest grain yield than the other varieties. There were significant differences among the varieties and between the locations. The grain yield at Jimah (4.0 t ha^{-1}) was almost double than in Sohar (2.22 t ha^{-1}) (MAF, 2011-15).

The newly developed wheat varieties, resistant to heat and diseases, are being evaluated. In the Wilayat of Adam, 2.30 tons seed of different wheat types was distributed among 16 farmers. The cultivated area expanded from 9.7 ha to 17 ha in 2018-19. However, the cultivation of wheat in the Wilayat of Adam faced some challenges, the most important of which is the lack of water and insufficient experience of workers in this field. The Ministry of Agriculture, Fisheries and Water Resources provided technical support to grow the wheat crop from the start of cultivation in November/December until the harvest in April. The crop is harvested in April with the use of modern combine harvesters.

Water Resources

To meet the increasing water demands of economical, industrial, and social developments the government of the Sultanate of Oman is exerting great efforts to develop water resources. Several programs on water resources development have been implemented, these include construction of dams and rainwater harvesting. Two types of dams are being constructed *viz.* recharge dams and flood protection dams. The recharge dams are constructed to enhance groundwater recharge through the use of valleys flood water which is often wasted in sea and desert. During 1985-2001, 39 recharge dams that have been constructed. About 14 flood protection dams are being constructed in Musandam and Muscat governorate to protect occupants of downstream areas from flood risks and can be used for recharge whenever possible (https://omanwires.com).

Extension Services

The weak agricultural extension system is also a serious problem in getting the required production targets (MAF, 2015). To attain self-sufficiency in food production, several projects were financed by the Agricultural and Fisheries Development Fund (AFDF). The AFDF has spent more than OMR 1.0 million in three stages to develop the cultivation and production of wheat in the Sultanate from 2006 to 2018 given of the importance of wheat crop to Oman. The main objective was to expand the area under wheat cultivation to decrease the wheat import in the country. The AFDF also provided support, guidance, high quality seed, and training to farmers in wheat cultivation to boost production. In addition to this, the basic tools and farm machinery were also provided to the farmers. Advisory services are also provided on the use of machines (for sowing and harvesting). Currently, the extension services in Oman have introduced modern irrigation systems. With the sprinkler system, significant progress has been made in the expansion of crop cultivation and production. The Ministry of Agriculture, Fisheries, and Water Resources has also issued a regulation to prohibit the use of agricultural lands for other purposes.

Challenges

Water Scarcity

Water scarcity is a major problem in wheat production in Oman. Oman is an arid country as the mean annual rainfall is < 100 mm and pattern of rainfall are irregular from year to year and most of the months remain dry throughout the year (Ahmed et al., 2013). However, in different parts of the country rainfall varies between 50 to 300 mm and Salalah is the only area where monsoon rains occur. The country is divided into very dry and dry parts (Hussain, 2005). Many regions in Oman are still characterized by a considerable year by year variability (e.g., Central, Northern, and Southern areas, and South-Eastern coast). In several regions, the monsoon climate and rainfall seasonality strengthen the impacts and effects of climate change. Along the South-Eastern coast, the recorded rainfall in autumn-winter is three times higher than the spring-summer. However, the summer and spring rainfall is equal to half of the autumn-winter rainfall. Generally, in the Central and Northern regions, the distribution of rainfall throughout the year is more evenly spread. The irrigated areas in Oman have been limited due to challenging climate mainly water scarcity (Zhou et al., 2010). Moreover, the environmental conditions are more unfavourable where human activities, vegetation, and grazing affect local environmental conditions. Indeed, the status of the natural resources as soil, vegetation, and water resources has been changed owing to production activities and increase in aridity.

Moisture deficit stress affect wheat growth at all stages and cause yield losses, however, flowering and grain-filling phases are more critical. The reduction in grain yield occurs as drought stress causes a decrease in net photosynthesis due to limitations in metabolic activities, stomatal closure, oxidative damage, and poor grain development (Farooq et al., 2014). In the country, crop production depends on wells (126 thousand ha) and Aflaj (19 thousand ha) for irrigation (MAF, 2013). The total water requirement of the country is 1430.2 million cubic meters, while available water is 1048.9 million cubic meters with the addition of 30 million cubic meters from sewage treatment annually and 8 million cubic meters from desalinization on daily basis contribute to the water need of the country. However, there is a short fall of 381.9 million cubic meters of the total water requirement (MRMWR, 2013). The most common irrigation technique is the traditional surface irrigation system covering 80% of the irrigated areas (FAO, 2008).

High Temperature

In summer, in the coastal areas, Oman has a hot and humid climate, while the interior part has a hot and dry climate. The mean temperature in June in Oman is usually 31-45°C, while in January temperature is mostly 20-25°C (https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine-in-Oman). However, the temperature during the wheat sowing (15^{th}-November to10^{th}-December) is usually higher than 25°C. The optimum temperature for anthesis and grain filling in wheat ranged between 12-22°C and temperature above this optimal range significantly reduced the grain yield (Farooq et al., 2011) owing to reduction in individual grain weight (Prasad and Djanaguiraman, 2014), which is due to leaf senescence and decreased grain filling duration (Asseng et al., 2011; Lobell et al., 2012). Moreover, a high temperature decreased floret fertility by affecting pollen and pistil morphology (Prasad and Djanaguiraman, 2014). As the temperature increases, the solubility of carbon dioxide decreases which reduced carboxylation and enhances production of electrons to form reactive oxygen species and photorespiration (Farooq et al., 2011).

Salinity

Salinity (both soil and groundwater) is another major bottleneck in successful wheat production in Oman. Of the total geographical area, 44% is salt affected and 70% of the agriculturally suitable land. The high temperature with little rainfall is main cause of salt accumulation in soil. The second cause of salt accumulation is the persistent use of saline groundwater by increased pumping (higher in Batinah region-productive area for agriculture). The intrusion of saline seawater.

In South Al-Batinah, 50% of the area is affected with slight to moderate salinity (EC > 4 dS m^{-1}). In North Al-Batinah, about 50% of the total cultivated area is irrigated with water having EC > 3 dS m^{-1} and 38% with

EC > 5 dS m^{-1} (MAF and ICBA, 2012)). The country's agriculture completely depends on irrigation and due to the absence of surface water bodies all irrigation occurs with groundwater drawn from sedimentary aquifers (springs). The use water level of the country now exceeds the long-term recharge (Omezzine and Zaibet, 1998; Al-Ajmi and Abdel-Rahman, 2001) which caused a decline of groundwater tables and intrusion of saline water into aquifers of the Batinah and Salalah coastal plains (Victor and Al-Farsi, 2001; Weyhenmeyer et al., 2002).

In wheat, salinity stress reduced the growth and yield by decreasing the germination, photosynthesis, and transpiration rate along with an increase in sodium (Na^+) and Cl^{-1} which disturbs the normal metabolic activities (Jafar et al., 2014; Tabasssum et al., 2017). During germination, salinity causes osmotic stress which imbalance the hormonal and enzymatic activities in seed reserves (Jafar et al., 2014) leading to poor germination. Under salinity stress, oxidative stress causes the production of reactive oxygen species as hydrogen peroxide, superoxide, and singlet oxygen which cause cellular damage to nucleic acid, proteins, and lipids in wheat (Afzal et al., 2013; Victor and Al-Farsi, 2001).

Low Yielding Varieties

The cultivation of low yielding local landraces and varieties is one of the major reasons for the low yield of wheat in Oman. In the past, the wheat varieties grown in the country had low yield potential and the first wheat variety Cooley which was released in 1970 had a yield potential of 1.96 t ha^{-1}. The potential yield of different wheat varieties (released from 1970-2019) varies between 1.96 to 5.2 t ha^{-1} (Table 1).

Unavailability of Climate Resilient Wheat Genotypes

As the climate of Oman is harsh, therefore the climate resilient crops perform well under these climatic conditions. In the case of wheat, the climate resilient genotypes as tolerant to drought, salt, and heat stresses are not available. For salinity tolerance, a little work on the screening of wheat genotypes was done in 1990s. However, till now there is no wheat genotype reported which have been developed in Oman for abiotic stress tolerance traits.

Lack of Rainwater Harvesting and Water Storage Bodies

There are 31 major recharge dams in the country since 1985 along with many small, structured dams which retain water at peak flows and are intended for groundwater recharge (FAO, 2008). However, to the best of our limited knowledge, there is no water reservoir for rainwater harvesting and storage for use in crop production.

Lack of Skilled farm Labor

Most of the farming in the Sultanate is subsistence farming where production is taken according to the family size or need. Many farmers cultivate small areas using a channel for water in Aflaj and the mountains. Most of the farmers, use family labour or hired labour which is mostly not skilled. The labour, working in different farms, is mostly non-skilled who cannot identify the critical stages of the crop to save it from stresses/losses as a critical stage of irrigation, fertilization, weeding, plant protection and harvesting. There is no regular training of the labour working on the farms. The use of skilled labour at the peak crop seasons (sowing, weeding, and harvesting) can help to increase crop production.

Modern Farm Machinery

Modern farm machinery is an important component of present-day agriculture to ensure food security. Farm machinery covers all the machinery which is used in farming from start to end user of the output. However, the unavailability of modern farm machinery for wheat in the country is also a problem in fulfilling the national wheat requirement. According to the agricultural census of 2012-13, the equipment used by farmers are tractors, hand plough, and combine harvester (MAF, 2013). The modern farm machinery e.g., seed drills, fertilizer drills, seed-cum fertilizer drills, bed planter, sub-soiler, boom sprayers, drip irrigation, mechanical weeder, and harvesters are not commonly available.

Substitution of Wheat with Fodder and Vegetable Crops

About 89% of the farms contain less than 2 ha where mainly alfalfa and annual grasses and vegetables are grown which occupy 24.6% of the total arable land (MAF, 2014). In 2015, the total fodder production was 1.77 Mt, and more than half (53%) was in the form of perennial fodder crops. The Rhodes grass was major fodder with 500,000 t (due to salt and drought tolerance) followed by alfalfa (278, 037 t), and sorghum (57,000 t). There was 54% increase in land area under fodder production between 2013 and 2105 with Rhodes grass (60%) and alfalfa (56%) (Oxford Business Group, 2020).

In the case of vegetables, an increase of 19% was noted in 2015 than the last year. Tomato was the leading vegetable crop with 116, 408 t production along with a 40% increase in area than 2014 (from 1296 ha to 1798 ha). The area under potato increased from 206 ha to 875 ha (Oxford Business Group, 2020). However, a 30% decrease in the area (from 5600 ha in 2013 to 3910 ha in 2015) under field crops (wheat, barley, and maize) was noted (Oxford Business Group, 2020).

Farm Size

Another major factor in low wheat production in the Sultanate is small landholding (< 2 ha) owing to the urbanization of different regions for residential colonies, infrastructure, and industrial purposes. The farm areas are shrinking due to population increase and conversion of farm areas to residential houses. As the 90% landholding size is < 2.02 ha and the landholding of > 4.05 ha are 5% (MAF, 2013). Moreover, the small landholder farmers cannot invest in farming due to less purchasing power for agricultural inputs, and competition with imported agricultural commodities.

Opportunities

Rainwater Harvesting and Storage

Rainwater harvesting is on-site accumulation of rainwater instead of running off that water. This can be collected from the roof tops or rivers/valleys. The construction of dams for rainwater harvesting and storage to collect the rainwater and to use that for wheat production can increase wheat production in the long run.

The dams as small retention dams, cisterns, and quarry pits can be used to harvest rainwater. In the center and north of Oman, the rainfall is received during winter season (November−April), while in south of the country (Dhofar), the summer monsoon (June−September) rainfall (300 mm) is received (FAO, 2008). This 300 mm rainfall water can be collected and stored for later use in wheat production.

Efficient Irrigation System

The use of traditional irrigation systems like wells and Aflaj causes heavy losses of water due to leakage and high evaporation. However, water losses can be reduced in modern irrigation systems and increase the availability of groundwater (Al-Mamary and Al-Kalabani, 2010). Efficient irrigation systems as drip irrigation and sprinkler irrigation systems are more productive in saving water and increasing crop production. According to the agricultural census of 2015-16, the 25 thousand ha (18%) of the total agricultural lands are irrigated with the modern irrigation system (MAF, 2015-16). However, there is still sufficient potential to increase this area to modern irrigation systems.

According to the Ministry of Agriculture and Fisheries, the use of modern irrigation systems can improve farmers' household income, crop availability in markets, and reduce water consumption (MAF, 2011). However, the adaption rate of efficient irrigation systems is low which can be increased by subsidies and awareness campaign from the government.

Development of Climate Resilient and High Yielding Wheat Genotypes

The 50% of water in wheat is lost with evaporation which reduces water use efficiency, which causes a decrease in grain yield and total biomass (Lopez-Castaneda and Richards, 1994). In Instituto Nacional, de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) in Mexico, the wheat breeding program had developed water efficient high yielding genotypes which are also rust resistant (Solis et al., 2008), by the introduction of such varieties the wheat production in Sultanate can be improved. Moreover, the resistant wheat genotypes produce good yield under arid environmental conditions. In a screening study of 96 wheat genotypes under drought stress, the 15 genotypes (LM03, LM04, LM15, LM22, LM23, LM27, LM29, LM31, LM35, LM44, LM71, LM77, LM85, LM96, and LM100) performed very good under drought stress for yield production (Mwadzingeni et al., 2016). The wheat genotypes tolerant to drought and heat stress are developed by CIMMYT' which are SM04, SM07, SM15, SM19, SM29, SM30, SM32, SM45, SM50, SM73, SM75, SM84, SM94, SM96, and SM97 (Mkhabela et al., 2019), which can be grown in the country to get self-sufficiency in wheat production.

The early maturing and high yielding climate resilient wheat genotypes produce higher yields under both optimal and suboptimal conditions. As in a study, Mondal et al. (2016) evaluated the progress in breeding for early maturing and heat tolerant CIMMYT wheat, adaption, and grain yield and found that early maturing and heat tolerant germplasm had higher grain yield than local check. The increase in grain yield in the genotypes varied between 104−116% compared to the local check. Under high temperature stress, early maturity is an excellent crop adaption mechanism in those regions where there is continuous high temperature (Joshi et al., 2007; Mondal et al., 2013). Similarly, the screening of diverse wheat genotypes under the environmental conditions of Sultanate Oman can benefit similar results and the best performing genotypes can be further used in breeding programs. In our field adaption trial of 218 diverse wheat genotypes (collected from different parts of the world) conducted during 2019-2020 at Agricultural Experiment Station, Sultan Qaboos University, Oman, we found that out of these 218 wheat genotypes, 150 genotypes performed excellent regarding grain yield under the natural conditions of Oman along with no disease attack (Farooq et al.; unpublished data). Breeding wheat genotypes for higher intercellular CO_2, photosynthesis, and water use efficiencies can increase grain yield and tolerance to drought and heat stress (Ullah et al; unpublished data).

The genetic potential of the existing national gene pool is very low as the genotypes developed from 1970 to 2019 have a yield potential of 1.96 to 5.2 t ha^{-1}. This potential can be increased by crop improvement (breeding), through screening of diverse wheat genotypes and by regional adaptability of these diverse genotypes. There is a need to screen diverse wheat genotypes for adaptability different parts of the country. The elite genotypes can be used in the national breeding programs to further improve the wheat genotypes. For instance, in India, the introduction of improved wheat varieties has increased the grain yield by 27% (Sonune and Mane, 2018).

In the Sultanate, various wheat varieties are grown, locally known as A'Sara'eea, Al Kuli, Al Hamira, Al Maysani, Al Walidi, Al Jareeda, and A'Shuweira. These varieties are well-adapted to the local conditions. However, these varieties mature late, have low productivity, and are susceptible to diseases. The use of introduced wheat varieties, like Wadi Quriyat 110, A'Sannin, Wadi Quriyat 226, Wadi Quriyat 302, and Wadi Quriyat 308 have shown good results for yield. The Ministry of Agriculture, Fisheries and Water Resources distributed > 10 new varieties (as Wadi Quriyat 226, A'Sannin, and Wadi Quriyat 308) to farmers in all governorates in the wheat growing season of 2018-2019.

Use of Modern Farm Machinery

In the success and adoption of a crop, the farm machinery is one of the key factors (Ullah et al., 2020). Farm mechanization is a tool to enhance the crop productivity and profitability (Verma, 2006). The modern farm machinery as laser land leveler, seed drills, fertilizer drills, seed-cum fertilizer drills, bed planters, tractor mounted tillage implements, boom sprayers, drip irrigation, mechanical weeder, and combine harvester, etc. can help boost the wheat productivity. The use of precision agriculture tools can also help improve the wheat productivity by optimizing the input use (European Agricultural Machinery, 2020). There exists a huge potential to enhance wheat production in Oman through use of modern farm machinery and precision agriculture tools.

Development and Dissemination of Site-specific Package of Production Technologies

The development and dissemination of site-specific production technologies package can boost wheat production in the country. For instance, late sowing of wheat causes a delay in germination, results in a sub-optimal plant population with a slower growth rate ends with a low grain yield due to sub-optimal temperature at sowing and at the reproductive stage. Similarly, selecting a wrong variety (not well-adapted), sub- or supra-optimal seed rate, imbalanced fertilizer use, over- or under use of irrigation water, lack of plant protection measures, and poor harvesting measures caused significant yield reduction. Developing, disseminating and adopting of a site-specific package of production technology can help increase grain yield significantly. For example, a 33% increase in wheat grain yield was recorded in a production technology transfer study of wheat in Faizabad District of Uttar Pradesh, India (Singh et al., 2016). Therefore, the development and dissemination of site-specific wheat production technology should be prioritized to increase wheat production in the country.

Seed Enhancements

Seed enhancement is the application of nutrients, fertilizer, microbes, and other chemicals through seed to improve the performance, yield, and quality of crops (Farooq et al., 2012). The poor plant population is one of the major reasons for low wheat yield in many situations. . Adverse field and environmental conditions, like soil salinity, above than temperature and soil moisture deficit, may affect the crop stand establishment that then affects the crop growth and yield. Under such circumstances, seed enhancement (priming and coating) is a cost-effective option to improve the germination, quality of seed and grain yield. Seed priming improves germination through earliness, uniformity, and better seedling emergence (Farooq et al., 2019). Moreover, seed priming with Zn and plant growth promoting rhizobacteria (PGPR) enhanced the grain yield in wheat (Rehman et al., 2018 a, b). Similarly, seed priming with Mn increased the grain yield of wheat (Ullah et al., 2018). Seed coating is an application of growth regulators, nutrients, and pesticides at the surface of seed through some stick material (Farooq et al., 2012). The increase in grain yield in many field crops as wheat, rice, chickpea, and cowpea through seed coating has been reported (Masuthi et al., 2009; Rehman and Farooq, 2016; Ullah et al., 2017, 2018; Farooq et al., 2018). The application of zinc seed coating (1.25–1.50 g Zn kg^{-1} seed) in wheat improved the emergence, grain yield, and quality of grains (Rehman and Farooq, 2016).

Conclusion

The production of bread wheat in Oman is less than 1% of the domestic requirements. Water deficits, salinity, heatwaves, prolonged droughts, unavailability of high yielding and stress resilient genotypes, and small and fragmented landholdings are major challenges of wheat production in Oman. Crop improvement programs should be initiated to develop high yielding, disease resistant and climate resilient wheat varieties well adapted to local conditions. High efficiency irrigation, principles of conservation agriculture, and seed enhancements may be included in the development and dissemination of site-specific packages of production technology. Strengthening the system of certified seed distribution and effective extension services may help farmers improve wheat productivity and profitability.

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