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Sustainable Durum Wheat (*Triticum durum*) Production for Enhancing Food Security in Palestine

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Abstract: To enhance the productivity of durum wheat, it is crucial to disseminate new and improved wheat varieties along with other enhanced crop management practices. The NARC, NGOs and local universities in collaboration with the ICARDA, has implemented various activities in Palestine from 2014 to 2022 to achieve this goal. The study aims to assess the outcomes of the activities focused on enhancing durum wheat productivity through the dissemination of new varieties and the implementation of improved crop management practices. A total of 920 farmers participated in the initiative for disseminating improved durum wheat. Additionally, 47 tons of high-quality seeds were distributed for 183 farmers. The implementation included demonstrations of recommended agronomic practices. Furthermore, more than 50 farmers engaged in farmer-participatory demonstrations focused on adequate nutrient management, specifically composting. The outcomes of the durum wheat dissemination revealed a notable improvement in the productivity of three durum wheat varieties, demonstrating an increase of 11.5% to 19.7% in both grain and straw yields, respectively, when compared to the control variety. The overall benefit for the new varieties amounts to approximately 1230 US $ ha^{-1}, whereas the control stands at about 901 US $ ha^{-1}, indicating a notable increase of 36.51%. The seed producers produced a total of 340 tons of high-quality seeds and 490 tons of straw. The total benefit from the difference between the agronomic and farmers package was about 208 US $ per hectare. The average increase in grain yield was 5% for compost practices, while the increase for straw yield was about 13%.

Keywords: Compost, Durum wheat, Improved packages, Profitability, Seed production.

Introduction

The agriculture plays an important role in the livelihoods of Palestinian farmers. As per the Palestinian Central Bureau of Statistics (PCBS) in 2018, the agricultural sector serves as the primary source of income for nearly 40% of households. According to the latest statistics from 2017/2018, the total area planted with field crops in Palestine reached 31,735.6 ha, with 89% of this area being rainfed (PCBS, 2023). Approximately 117,141 ha are dedicated to the cultivation of wheat,

yielding around 79,913 tons annually according to the Palestinian Ministry of Agriculture (MoA) in 2023. (MoA, 2023). Durum wheat (*Triticum turgidum*) is one of the most essential cereal species and is cultivated worldwide. Canada currently holds the leading position in global durum wheat exports, contributing to approximately half of the total durum wheat available for export. Additionally, Mexico and Canada contribute 17% and 16%, respectively, according to the International Grains Council (IGC) in 2020 (Beres *et al*., 2020). Enhancing durum wheat is crucial not only for increasing productivity but also for adapting to local biotic and abiotic stress conditions (Beres *et al*., 2020). Various public research institutes have undertaken breeding initiatives for durum wheat, initially employing landraces as the foundational materials in improvement programs and incorporated parent varieties with diverse and beneficial agronomic characteristics in the crossing process (Xynias *et al*., 2020). The adoption of new crop varieties alone is insufficient to achieve substantial increases in yields. To realize significant gains, concurrent attention to increased input utilization, especially in the application of fertilizers, is essential (Bhardwaj *et al*., 2021; Du *et al*., 2021). In the context of rainfed agriculture, improved varieties and appropriate inputs are vital components of cropping systems aimed at enhancing yield potential (Joshi *et al*., 2016; Aune *et al*., 2019; Grote *et al*., 2021). Given that, the majority of production inputs and supplies are imported in Palestine. Therefore, the Agriculture Sector Strategy in Palestine for 2021-2023 emphasizes a high priority on reducing the agriculture sector's dependence on commercial imports, particularly for inputs such as fertilizers and seeds. In addition to increase productivity, cereals including wheat, play a vital role in food security, contributing significantly to daily calorie and protein intake (Tadesse *et al*., 2017). In response to population growth, increasing wheat productivity becomes essential, this objective aligns with broader aims of food system transformation and overall development (Rodríguez *et al*., 2020). To achieve these goals, the Ministry of Agriculture (MoA) through the National Agricultural Research Center (NARC) collaborated with International Center for Agricultural Research in the Dry Areas (ICARDA), local Non-Governmental Organization (NGOs) and local universities (2013 to 2021) implemented various projects and activities to enhance the production of durum wheat in Palestine and address food insecurity. The expansion of the utilization of improved varieties, landraces, and quality seeds for increased productivity is seen as a strategy to empower farmers to better manage production shocks and variability. The current study aims to assess the outcomes of these activities focused on enhancing durum wheat productivity during the years 2010 to 2022 through the dissemination of new cultivars and the implementation of improved crop management practices.

Methodology

The projects target areas

The areas targeted by the initiative include Jenin, Tubas, Nablus, Hebron, and Ramallah, covering a total area of 4010.8 km^2 (Fig. 1). This region extends from the north to the south of the West Bank and contributes to approximately 90% of Palestine's durum wheat production. Concerning rainfall in the target area, annual precipitation varied each year, with average amounts of 468.5 mm, 431 mm, 660 mm, 615 mm, and 595 mm in Jenin, Tubas, Nablus, Ramallah, and Hebron, respectively (Fig. 2).

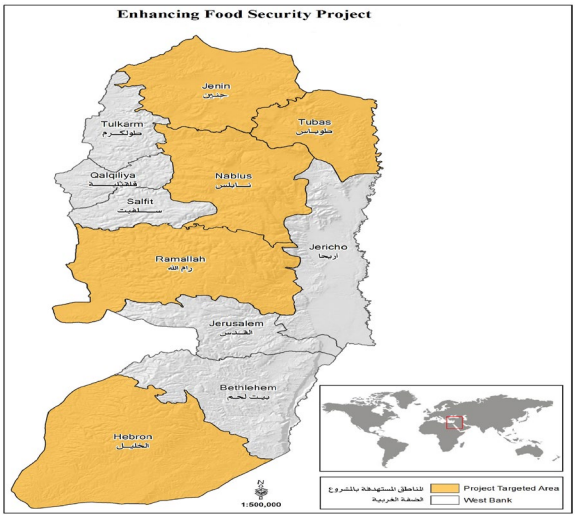

Fig. (1): The map of the identified project target areas.

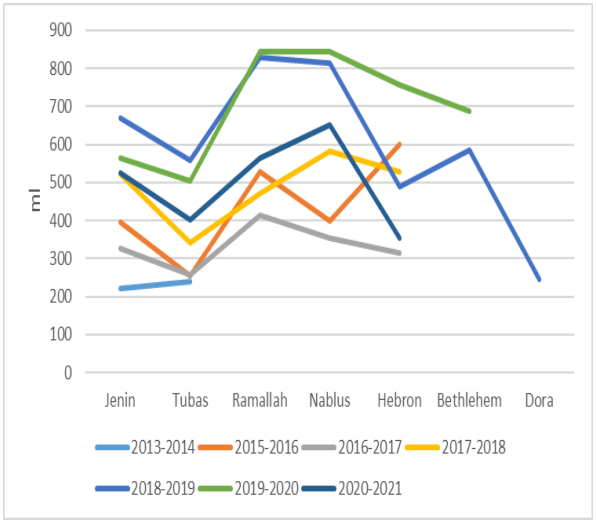

Fig. (2): The rain fall for the target sites from 2013-2021.

Dissemination of tested improved wheat varieties to the farmers in Palestine

A total of 32 wheat varieties introduced and assessed across Tubas, Jenin, and Ramallah sites from 2010 to 2014. The most successful durum wheat varieties outperforming the control were extensively distributed to farmers during the 2014/15 growing season. Approximately 30 farmers engaged in this initiative, planting the six improved varieties across a combined area of 30 ha, with each farmer contributing 1 ha. Additionally, 15 ha of the control variety were cultivated in the same fields (0.5 ha per farmer). Between 2016 and 2022, the introduced varieties were consistently compared with a common wheat genotype used as a control by farmers. A total of 920 farmers from the targeted governorates participated in this endeavor (Fig. 3).

A total of 138 tons of high-quality seeds were distributed for cultivation on 920 ha during the seasons (2014–2022). Additionally, 46 tons of fertilizers and 1840 liters of 2,4D herbicide were used in the same period.

Production of high quality seeds

To address the challenge of limited availability of high-quality seeds, which hampers agricultural productivity, support of farmers was conducted for seeds multiplication using Simi formal seed production approach.

Researchers and extension agents visited communities in the three governorates (Tubas, Jenin and Hebron) and established seed producers' groups in Hebron, Tubas and Jenin as described by Ayana *et al*. (2013). In total 47 tons of high quality seeds was distributed for 183 farmers with an area about 300 ha during 2014 to 2022, but after the visit of the fields and monitoring the seed production just 65 farmers was selected. Training sessions were provided to enhance the seed producers' capacity for high-quality seed production. Inspections, including laboratory tests, were conducted, and certificates were awarded to fields that met the required standards. Sixteen meetings were held with farmers across different governorates, focusing on seed production quality, quantity, and field management. The data has been collected regarding the amount of high-quality seed produced and marketed.

Demonstrating recommended agronomic practices

The economic agronomic package was evaluated under farmers' conditions. Wheat under recommended package performed better than wheat grown under farmers' traditional practices in term of grain production. This economic package was disseminated on large scale to cover more farmers from the different governorates as shown in the table (1). In total 90 farmers in the five governorates were involved in this activity. Each farmer divided 1 ha of his land into two parts. The first part was managed according to the recommended practices and the second part was cultivated according to farmers' practices. All farmers were provided with seeds, herbicides, fertilizers and technical support.

Table (1): Recommended agronomic package versus farmer's practices.

No	Application	Farmers' practices	Agronomic package
1	Seeding rate	200 kg ha^{-1}	130 $kg.ha^{-1}$
2	Weeding	-	Herbicide (2-4-D)
3	Fertilizers	150 – 200 kg ha^{-1}	120 $kg.ha^{-1}$
4	Sowing date	1- 15 December	1-10 November
5	Wheat varieties	Anber	Mike
6	Seeding	Manual	Seeder

Farmer-participatory demonstration of adequate nutrient management (compost) in combination with crop rotations.

This activity introduced due to the limited availability of chemical fertilizers sources and also as a step toward an organic farming approach and protection of the environment, therfore, compost fertilizer were used to replace chemical fertilizers. The compost was prepared with the farmers participation where the projects team demonstrated the process of compost manufacturing in Tubas, Jenin and Ramallah governorates. Materials for the compost pile were collected and prepared, including potato and tomato by-products, cow manure, hay, powder from stone crusher, small branches of trees, and water. Layers of animal and plant by-products, straw, and powder from a stone crusher were systematically arranged to enrich the pile with minerals. A soft layer of soil was used to cover the piles, which were then moistened with water and periodically mixed to enhance composting efficiency. In total 50 farmers joind this activity (one ha). The field of each farmer was divided into two parts, one part for compost farming and an other part for conventional farming. Sum of 7500 kg of high quality seeds were distributed to the farmers from Tubas, Jenin and Ramallah governorates and 4500 kg of initial fertilizers (Superphosphate and ammonium sulfate) were also distributed (Table 2).

Profitability

The profitability is the ability of the seed business to generate revenue over and above its expenses to help the stakeholders to analyze and measure the ability to generate revenue to cover the operational cost. The profitability was calculated for each activity. The data on the inputs and return was collected each year.

Data collection and analysis

The data was collected on grain and straw yield for each activity to compare it with farmers practices. Means, standard deviation, T Test and ANOVA were calculated to find out the significant differences using SPSS package. Finally, fig. (3) presents a chart illustrating the steps and activities undertaken during the food security project period.

Table (2): Number of farmers, number of varieties, seeds (kg), amount of fertilizer and planted area (ha) distributed.

Sites	No. of farmers	No. of Varieties	Amount of seeds (Kg)	Amount of initial fertilizers (Kg)	Planted area (Ha)
Tubas	18	4	2700	1550	18
Jenin	18	4	2700	1550	18
Ramallah	9	4	1350	900	9
Nablus	5	2	750	500	5
Total	50		7500	4500	50

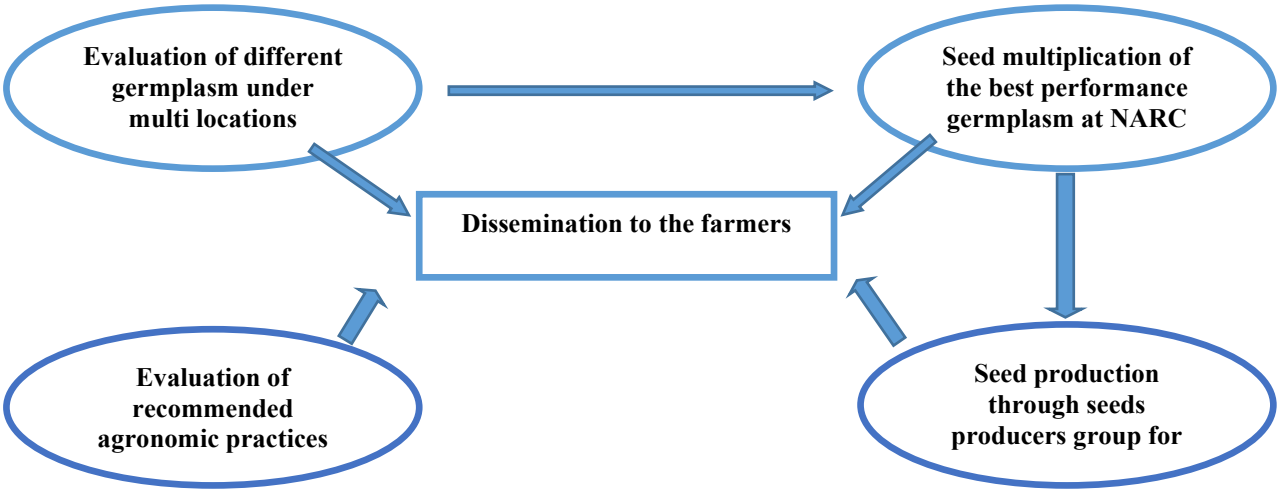

Fig. (3): Projects approach flow chart.

Results & Discussion

Average grain yields of introduced wheat varieties within the sites

Between 2015 and 2022, the top three widely disseminated wheat varieties (Figs. 4 & 5) exhibited significant increases (Table 3) in both grain and straw yield averages compared with the control variety. Specifically, for Ammar, Mike, and Um Rabea, the average increase in grain yield was 13.4%, 19.2%, and 19.7%, respectively, while the average increase in straw yield was 11.5%, 11.5%, and 12.5%, respectively. The enhanced yield observed in the Ammar, Mike, and Um Rabea varieties is expected. ICARDA has played a pivotal role in the development and testing of these varieties through its durum wheat program. Annually, ICARDA supplies germplasm to a diverse range of partners crossing 32 countries, Palestine included. The ICARDA durum wheat program employs a strategy that involves utilizing wild relatives, primitive varieties, and collected landraces to generate novel varieties. This approach has resulted in a significant increase, exceeding 0.7%, in the average annual rate of genetic gain (ICARDA, 2022).

Table (3): ANOVA analysis for grain and straw yeild of wheat varieties (t ha^{-1}).

Variable	df	Mean Square	F	Sig.
Grain yield	3	.300	3.821	.023
Straw yield	3	.378	5.935	.004

Profitability and return

The expenses incurred on inputs primarily

influence the cost and returns of crop production. In the present study, the economic return for wheat seed evaluated. The highest average production input cost was associated with harvesting, amounting to approximately 236 US $.ha^{-1}, followed by the cost of fertilizers at about 230.7 US $.ha^{-1} (Table 4). Consequently, the returns from the new varieties showed a 15% increase over the control variety (Table 5).

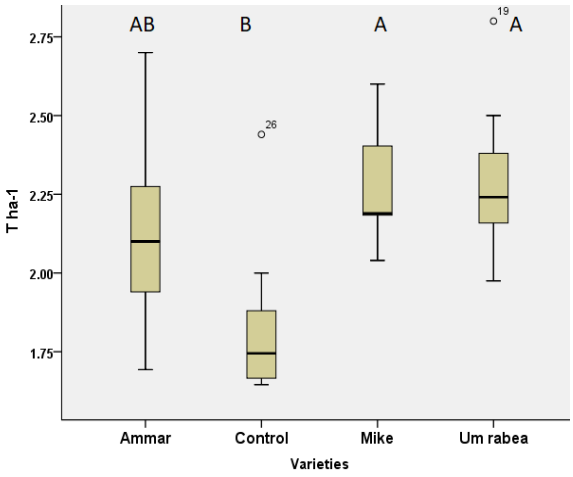

Fig. (4): Average increase in grain yield for Ammar, Mike, Umrabea, and Anbar (control variety).

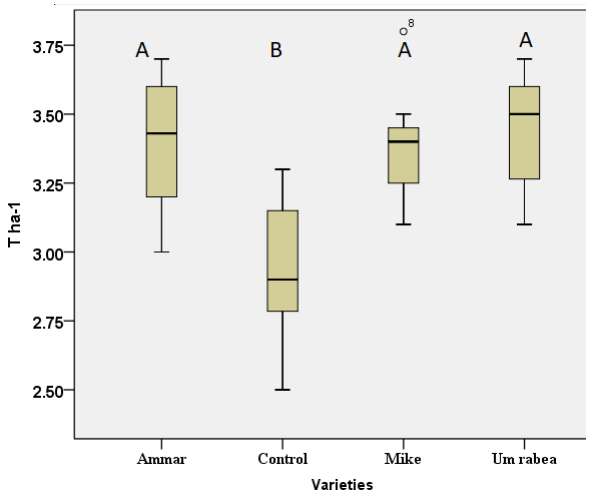

Fig. (5): Average increase in straw yield for Ammar, Mike, Umurabi, and Anber (control variety).

Table (4): Cost of agricultural inputs (US $ ha^{-1}).

Item	Cost in US $.ha^{-1}
Plowing	105.2
Fertilizers	230.7
Seeding	80
Seeds	148.2
Pesticide	50
Harvesting (grain and straw)	236
Labor	120
Total	**970.1**

Table (5): Economic returns from cultivating introduced varieties compared to common variety (US $.ha^{-1}).

Item	Grain yield	Straw yield	Total
Return from new varieties	1257.1	942.86	2200
Return from the control	1028.6	842.86	1871.4

Benefit

The new wheat varieties yielded an average benefit of approximately 1230 US $.ha^{-1}, while the control variety yielded about 901 US $.ha^{-1}, indicating a remarkable increase in profitability. These findings agreed with those of Joshi *et al*. (2016) who observed a highly significant difference in yield and economic returns between new and traditional wheat varieties. Consequently, the results suggest that the new wheat varieties offer a significant economic benefit over the traditional varieties. Farmers who adopt the new varieties can expect to get an increase in their profits of up to 36.51%.

The production of high quality seeds by seed producers

In addition to the 490 tons of straw produced, farmers generated a total of 340 tons of high-quality seeds during 2014 to 2022. More than 80% of the seed was sold, either directly to other farmers or through NGOs. The used approached of Simi and informal seed

production was also succeed to produce high quality seeds in many developing countries including Afghanistan (ICARDA, 2023)

The recommended agronomic practices

Significant variation ($P < 0.05$) among wheat varieties observed for both grain and straw yield. Consequently, the genotypes were significantly interacted with all of the locations for grain and straw yield. The agronomic package, specifically the Mike variety, demonstrated the highest average grain yield at 2.8 t.ha^{-1} in the Jenin site. Similarly, the highest average straw yield, reaching 7.3 t ha^{-1}, was also observed for the same agronomic package (Mike) at the Jenin site (Table 6). This increase in Jenin was due to the experience of Jenin farmers in field crop production followed by Tubas farmers. Where endogenous knowledge accumulated in Jenin and Tubas in field crop production.

Table (6): Over all means of wheat varieties grain and straw yield (t ha^{-1}) in Tubas, Jenin, Ramallah, Hebron and Nablus governorates.

Site	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	Farmers package	Agronomic package	Farmers package	Agronomic package
	Anber	Mike	Anber	Mike
Tubas	1.7 ± 0.3a	1.9 ± 0.5b	5.8 ± 0.7a	6.8 ± 0.67b
Jenin	2.3 ± 0.52a	2.8 ± 0.42b	6.0 ± 0.84a	7.3 ± 0.58b
Nablus	1.4 ± 0.2a	1.4 ± 0.37a	2.2 ± 0.5a	2.1 ± 0.8b
Ramallah	1.6 ± 0.25a	1.7 ± 0.15b	2.1 ± 0.4a	2.3 ± 0.6b
Hebron	1.7 ± 0.33a	1.7 ± 0.4a	2.1 ± 0.6a	2.2 ± 0.45b
Average	1.7 ± 0.32a	1.9 ± 0.37b	3.7 ± 0.6a	4.3 ± 0.62b
P value of T test	**0.003**		**0.001**	

Profitability and return

The total reduction in production costs amounted to 94 US $, as shown in table (7), which displays the cost comparison between farmers' practices and proposed practices. Harvesting, at 236 US $, represented the highest cost. The return from grain and straw yield for the proposed practices exceeded that of farmers' practices by approximately 33 US $ and 81 US $, respectively.

Table (7): Cost of agricultural inputs for farmers and proposed practices (US $ha^{-1}).

Item	Farmers practices $ ha^{-1}	Proposed practices $ ha^{-1}
Plowing	105.2	105.2
Fertilizers	230.7	115.3
Seeding	0	40
Seeds	128.2	83.3
Pesticide	0	50
Harvesting	236	236
Labor	120	60
Bales	217	254
Total	**1037.1**	**943.8**
Difference	**94**	

Benefit

The total benefit from the difference between the agronomic package and the farmers' package was 208 US $ per hectare. This agreed with the findings of Baudron *et al*. (2019), who observed that wheat productivity could be increased by implementing an improved package involving seeding rate, nitrogen application, frequent weeding, and labor-saving technologies.

Farmer-participatory demonstration of adequate nutrient management (compost) in combination with crop rotations

The average increase in grain yield found to be 5% for compost practices, while the increase in straw yield was approximately 13% (Table 8). Compost fertilizers increase sustainability of wheat production and improve grain quality and nutritional value as an alternative source for nitrogen fertilizers. The considerable increase in yield could be primarily attributed to the beneficial impact of compost on soil physical properties. Compost's capacity to improve soil structure promotes a favorable environment for root growth, increasing the absorptive surface area for nutrient uptake. This uptake process is directly influenced by both dry-matter production and nutrient concentration. This explanation is consistent with Verma *et al*. (2016) findings.

Table (8): Over all means for wheat varieties for grain and straw yield (t.ha^{-1}) in Tubas, Jenin, Nablus and Ramallah governorates.

Site	Grain yield (t.ha^{-1})		Straw yield (t.ha^{-1})	
	Compost practice	Farmers practice	Compost practice	Farmers practice
Jenin	2.0 ± 0.2a	2.0 ± 0.27a	5.5 ± 0.5	4.7 ± 1
Tubas	1.7 ± 0.33a	1.6 ± 0.4b	3.6 ± 0.6	2.9 ± 0.57
Nablus	1.5 ± 0.16a	1.5 ± 0.18a	1.7 ± 0.3	1.7 ± 0.24
Ramallah	1.8 ± 0.17a	1.7 ± 0.21b	2.9 ± 0.17	2.7 ± 0.15
Average	1.8 ± 0.21a	1.7 ± 0.26b	3.8 ± 0.39	3.3 ± 0.38
P value of T test	**0.02**		**0.012**	

Different letters in each column means significant differences are found among treatments at P≤ 0.0.5.

Profitability and return

The total reduction in production costs amounted to 136.6 US $, as illustrated in table (9), which displays the cost comparison between farmers' practices and proposed practices. Harvesting, at 236 US $, represented the highest cost. The return from grain and straw yield for compost practices exceeded that of farmers' practices by approximately 45 US $ and 58 US $, respectively.

Benefit

The comprehensive assessment of agricultural practices revealed a substantial total benefit associated with the incorporation of compost, amounting to 239.6 $ ha^{-1} in comparison with farmer's practice. This economic advantage underscores the potential of compost application in enhancing agricultural productivity. Notably, these findings was agreed closely with the research outcomes reported by Singh *et al*. (2021). Additionally, it is worth mentioning that composts derived from plant residues serve as cost-effective fertilizers widely utilized in various regions (Bezabeh *et al*., 2022).

Table (9): Cost of agricultural inputs for farmers' and compost use (US $.ha^{-1}).

Item	Farmers' practices	Compost application
Plowing	105.2	105.2
Fertilizers	230.7	64
Seeding	89.7	89.7
Seeds	128.2	83.3
Pesticide	50	50
Harvesting	236	236
Labor	60	60
Bales	165	190
Total	1014.8	878.2
Deference	**136.6**	

Conclusions

For development sustainable durum wheat production to increase food security in Palestine, it is necessary to enhance farmer access to high quality seed of improved varieties. In addition to the use of improved packages of proper seed rate, time of planting, quantity of seed and fertilizer and the application of weed control. The use of organic fertilizer is also important to improve the productivity by using environment friendly solution. To establish sustainable durum wheat production and enhance food security in Palestine, it is crucial to augment farmers' access to high-quality seeds of superior varieties. This necessitates the implementation of improved practices such as optimal seed rate, time of planting, appropriate seed and fertilizer quantities, and effective weed control. Additionally, the adoption of organic fertilizer plays a pivotal role in improve productivity through environmentally conscious solutions.

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Contributions of authors

Y.H. and **A.A.** designed and carried out the study. **A.A., S.J.** and **N.A.** carried out the fieldwork. **A.A.** carried out the statistical analyses and interpretation of the study. **Y.H.** and **A.A.** wrote and reviewed the first and the final draft of the manuscript. The authors read and approved the final manuscript.

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Conflicts of interest

The author declares that there is no conflict of interest.

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الانتاج المستدام للقمح القاسي (*Triticum Durum*) لتعزيز الأمن الغذائي في فلسطين

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المستخلص: لزيادة إنتاجية القمح الصلب ، يجب العمل على نشر أصناف قمح محسّنة جديدة جنبًا إلى جنب مع تطبيق ممارسات زراعية مبتكرة. من أجل ذلك عمل المركز الوطني الفلسطيني للبحوث الزراعية (NARC) بالشراكة مع مؤسسة إيكاردا بتنفيذ أنشطة عملية لتحقيق ذلك في فلسطين وذلك خلال الفترة من 2014 إلى 2021. وقد شارك 920 مزارعًا من المحافظات الفسطينية المستهدفة في نشاط نشر أصناف جديدة من القمح الصلب. لقد تم توزيع 47.25 طنًا من البذور عالية الجودة على 183 مزارعًا، كما انضم أكثر من 50 مزارعًا إلى نشاط الإدارة الصحيحة للمغذيات (السماد العضوي) جنبًا إلى جنب مع تأهيل وتدريب المزارعين. وقد تم حساب الربحية أيضًا لكل نشاط. أظهرت نتائج نشر أصناف جديدة من القمح القاسي المحسن الى زيادة في إنتاجية ثلاثة أصناف من القمح القاسي من 11.5 إلى 19.7٪ لإنتاج الحبوب والقش مقارنة بالصنف الشاهد. تبلغ الفائدة الإجمالية للأصناف الجديدة حوالي 1230 دولارًا أمريكيًا للهكتار بينما تبلغ الفائدة حوالي 901 دولارًا أمريكيًا للهكتار مما يعني زيادة بنسبة 36.51٪. تم إنتاج 800 طن من البذور عالية الجودة من قبل منتجي البذور بالإضافة إلى 950 طن من القش. لوحظ وجود فروق معنوية (علامة> 0.05) لإنتاج الحبوب والقش بين ممارسات المزارعين وبين الحزمة الزراعية المحسنة. كما وتتفاعل الاصناف المحسنة بشكل معنوي مع المواقع لإنتاج الحبوب والقش. بلغ إجمالي الفوائد للفرق بين الحزمة الزراعية وحزمة المزارعين حوالي 208 دولارات أمريكية للهكتار. ولوحظ وجود زيادة في متوسط إنتاج الحبوب نتيجة لممارسات إضافة السماد العضوي (الكومبوست) بنسبة 5٪ بينما كانت الزيادة في إنتاج القش حوالي 13٪.

الكلمات المفتاحية: القمح الصلب، إنتاج البذار، الحزمة المحسنة، الربحية، الكومبوست.