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RESEARCH ARTICLE

Impact of improved agricultural extension approaches on technology adoption: Evidence from a randomised controlled trial in rural Tunisia

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Summary
Low and slow adoption of innovative technologies among smallholder farmers in Tunisia is a key agricultural development problem partly related to the existing technology transfer approach used in the country. The objective of this study is to analyse how to design innovative technology transfer strategies more effective in terms of increasing female and male farmers' adoption of an improved barley variety, 'Kounouz', for small ruminant nutrition. A randomised controlled trial method was used with farmers in Tunisia to implement four extension treatments and to evaluate their effects on adoption of Kounouz. Difference-in-difference estimates showed that intensive agricultural trainings can significantly improve adoption of Kounouz. Technical trainings combined with economic and organisational training and female empowerment courses resulted in a higher adoption rate. This finding has important policy implications, because it suggests that ensuring more widespread and equitable adoption of improved technologies may not require changes in the research system, but rather introduction measures that ensure better access for women to gender-sensitive extension programmes given their positive impacts on technology adoption of the household.

Keywords: Agricultural extension; Improved variety; Technology adoption; Female empowerment; Trainings; Randomised controlled trial; Tunisia

Introduction

Traditionally, Tunisia's agricultural system is based on small family farms that grow subsistence crops with little market integration (Blom-Zandstra *et al.*, 2017). Despite agriculture's contribution to the economy, a high proportion of Tunisia's rural population continues to have low incomes and poor living conditions (Moyo *et al.*, 2019).The agriculture sector faces technical and institutional challenges, which include limited access to credit, especially for small-scale farmers, weak farmers' organisations, a weak partnership and collaboration between research and extension, poor technology transfer structures and patterns leading to low and slow adoption of agricultural innovations, as well as low capacities of the existing extension services

(ICARDA, 2020).Nearly 80% of the rural population rely on traditional methods of production and the level of productivity is low. Livestock contributes 41% of the country's total agricultural production and represents around 4% of GDP (INS, 2016). The sector plays a critical role in the overall food system, because livestock activities are mainly undertaken by smallholder farmers with a low level of productivity.

Technology adoption by smallholder farmers is crucial for agricultural modernisation, productivity enhancement and economic prosperity in less developed countries (Marenya and Barrett, 2007; Noltze *et al.*, 2012). Improving agricultural productivity plays a key role in maintaining livelihoods and ensuring a robust food supply to sustain national development and growth. However, despite the potential of agricultural technologies to increase productivity, incomes and food security, technology adoption rates by smallholder farmers in Tunisia remain very low (Dhraief *et al.*, 2019). This 'adoption gap' is not only observed in Tunisia but is typical for agricultural system innovations and natural resource management technologies in many other developing countries (Shiferaw *et al.*, 2009; Noltze *et al.*, 2012).

Key to the continued contribution of agriculture to Tunisia's economy and beyond is the adoption of new management, communication, innovation and production practices, which are expected to maintain long-term profitable agricultural operation (Collier and Dercon, 2014). A major challenge remains, however, to design appropriate efficient and cost-effective technology transfer systems.

Anandajayasekeram *et al.* (2008) defines agricultural extension as the delivery of relevant agricultural information and technologies to farmers. Existing technology transfer models of agricultural extension (Dhehibi *et al.*, 2019) are based on the premise that 'modern' knowledge and/or information is transferred via extension agents to recipient farmers. For example, at the national level in Tunisia, despite the involvement of the private sector, the technology transfer system is formally driven by public authorities through various extension and training support structures. However, a recent study assessing the status and functioning of extension organisations in Tunisia revealed a number of strengths, weaknesses, opportunities and threats and highlighted possible approaches to make these organisations more service delivery-oriented (Dhehibi *et al.*, 2019).

Traditionally, agricultural extension was often implemented through extension officers visiting individual farmers to give advice on specific topics (Anderson and Feder, 2004). In Tunisia, the technology transfer system is essentially driven by public authorities through various support structures, in particular the General Directorate of Agricultural Production, the Regional Commissions for Agricultural Development, the Agricultural Training and Extension agency (AVFA) and the Office of Livestock and Pasture (Office de l'Elevage et des Pâturages or OEP). It is noteworthy that small, poorer, remotely living and female farmers do not have access to the official extension system. The Institution of Agricultural Research and Higher Education in Tunisia covers the National Agricultural Research System (NARS) consisting of four complementary sets of structures providing necessary support for agricultural research: research institutes, institutes of higher agricultural education, regional hubs for research and development, and work of experimental stations (Khaldi *et al.*, 2010).

New extension approaches need to emerge locally, based on experimentation, learning and adaptation to prevailing as well as evolving conditions. The discussions and interactions with key stakeholders involved in the extension information chain suggest that extension should be demand-driven and staff should receive appropriate training to carry out their duties (Thabet *et al.*, 2015). They also reveal that scarce resources can be used more effectively through partnerships with the private sector and use of information and communication technologies where appropriate. Finally, it is critical to note that monitoring and evaluating performance of extension service delivery based on stakeholder feedback is also crucial in ensuring that extension staff skills remain relevant to extension services end-users' needs (Dhehibi *et al.*, 2019).

The question of how to design innovative and cost-effective technology transfer systems in Tunisia has not yet been sufficiently addressed. While previous studies have analysed how agricultural and vocational training components could be improved to increase farmers' adoption of agricultural innovations (Thabet *et al.*, 2015), we are not aware of research that has developed and tested new extension approaches for the effective dissemination of improved crop varieties technologies. Here, we address this research gap with a randomised controlled trial (RCT) in Tunisia. In particular, we evaluated how agricultural training can be combined with economic and organisational training and female empowerment to increase farmers' adoption of improved barely variety, such as Kounouz crop. RCT is often called the 'gold standard' of evaluation methods, as it is the only method that allows a comparison of outcomes with and without a particular intervention, while avoiding selection bias due to observed or unobserved factors. This study compares different extension methods and evaluates their impacts on technology adoption rates and farm household livelihoods. In addition to agricultural training, the tested extension methods include training for farmers on business enterprising, organisational aspects and a female empowerment training component. The extension methods were tested in the context of reducing livestock feeding costs in barley–sheep farming systems in semiarid Tunisia (Dhehibi *et al.*, 2019). Although the concrete results of our research are specific to the study area in semiarid Tunisia, lessons learned from this investigation will be useful for the Middle East and North Africa region which faces similar challenges.

Materials and Methods

Description of the study area

The study area involves two governorates with similar agro-ecological conditions: Zaghouan and Kairouan which are characterised by a semiarid climate and average rainfall ranging from 200 mm in the south to 450 mm (Fig. S1). The main cereal crops grown are wheat, barley and oats, usually integrated with small ruminants (sheep and goats). In addition to the limited natural resources, particularly arable land and water, a large number of small farmers derive most of their family income from barley/livestock-based systems and sheep fattening practice is quite profitable in the two regions.

Sampling and sample size

The data of the study are based on a survey of 700 households from 70 villages across the2 governorates and collected by ICARDA in collaboration with OEP. The sampling procedure used in the selection of households for the study was as follows: first, households were identified based on the following criteria: (i) ownership of 0–5 ha of land and (ii) ownership of 1–50 small ruminants. Villages where at least 10 farmer households fulfilled both criteria were selected. Second, 10 households of the same village were put in 1 group, such that 70 villages each with 10 farmer households were selected from the 2 governorates. Finally, farmers were divided into 5 treatment groups comprising 140 households each (or 14 villages), leading to the sampling of 700 households. The households selected included both male and female household heads.

Types, sources and data collection procedure

Before starting data collection, potential innovative technologies to be tested by the project were intensively discussed with National Agricultural Research and Extension Services partner organisations including the National Institute of Agricultural Research of Tunisia (INRAT), OEP and AVFA. This led to the selection ofa new barley variety called *Kounouz*. Compared to commonly used barley varieties, this improved variety significantly boosts yields in arid areas given its high resistance to climate change-induced drought and diseases (Dhehibi *et al.*, 2019).

The survey was implemented in two rounds. The baseline round was conducted during November–December 2016. The follow-up survey was conducted during November–December

2018, after the experimental treatments were completed. Due to sample attrition, the follow-up round included observations from 671 farm households. For the evaluation, a balanced panel of 671 observations with complete data for both survey rounds was used as this allowed employing difference-in-difference techniques. Data from sample households were collected through face-to-face interviews with the household head and/or the spouse using a structured questionnaire which was administered in the local language. The questionnaire was divided into 17 modules covering all variables that can potentially influence the adoption of agricultural technologies by smallholder farmers (AppendixS1).

Empirical settings

This study was conducted as part of an ICARDA-led research for development project entitled '*Mind the Gap: Improving Dissemination Strategies to Increase Technology Adoption by Smallholders*' (https://mel.cgiar.org/projects/mindthegap) implemented in Tunisia during the period 2016–2019. The RCT method was used with smallholder farmers in Tunisia to implement four extension treatments and to evaluate their effects on the adoption of these technologies. Almost 62% of farmers are smallholders with less than 10 ha each. Approximately 25% of the rural population is landless. Technology adoption remains low in many developing countries in arid environments (Shiferaw *et al.*, 2009) including Tunisia (Dhraief *et al.*, 2019). Our RCT focuses on the adoption of an improved variety of barley with an increased resistance to the impacts of climate change, specifically drought, in study areas.

Data analysis and presentations

Data for the impact analysis were collected through a follow-up survey. Both qualitative and quantitative data were fully analysed. Content analysis suited the qualitative data, while quantitative data were analysed through Statistical Package for Social Science (SPSS) software version 21 for generating descriptive and inferential statistics that helped to make linkages of study variables. Finally, the outputs are presented in tables for easy interpretation.

Experimental design

The 'Mind the Gap' research project tested new and existing models of transferring innovative technology packages to smallholder farmers by using a RCT approach. The technology transfer models we tested comprised four components: access to inputs, access to technical information, access to organisational and economics training, and female empowerment. These four components were combined in various ways, and the combinations were implemented in four treatment groups to test and compare their individual and combined effects.

Treatment arms and implementation

Our RCT included four treatment arms, each with a different extension approach. The first treatment included technical training only and the other treatment groups received technical training plus at least one additional component. Around 560 farmer households of four treatment groups (T1–T4) were invited to participate in technical training activities (Table S1)

Technical training in Treatment 1 was offered to 137 farmers divided in 107 farmers from 11 villages in Kairouan and 30 farmers from 3 villages in Zaghouan. Technical training and economic and organisational (Treatment 2) training were offered to 137 farmers shared in 47 farmers from 5 villages in Kairouan and 90 farmers from 9 villages in Zaghouan. In Treatment 3, 137 farmers were attended the technical training, economic and organisational training and female empowerment training divided in 77 farmers from 8 villages in Kairouan and 60 farmers from 6 villages in

Table 1. Mean adoption rates at baseline and follow-up surveys

	Variables	All	Control	T1	T2	T3	T4
Baseline	*Kounouz* adopter (dummy)	0.010 (0.100)	0.000 (0.000)	0.014 (0.119)	0.014 (0.119)	0.014 (0.119)	0.007 (0.085)
	Observations	700	140	140	140	140	140
Follow-up	*Kounouz* adopter (dummy)	0.181 (0.385)	0.077 (0.268)	0,226 (0.420)	0.244 (0.431)	0.335 (0.474)	0.139 (0.347)
	Observations	671	129	137	137	137	131

Notes: Mean values are shown with standard deviations in parentheses. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.

Zaghouan. Technical training and female empowerment training were offered in Treatment 4 to 131 farmers divided in 122 farmers from 13 villages in Kairouan and 9 farmers from 1 village in Zaghouan. The control group was composed of 129 farmers distributed between Kairouan (101 farmers from 11 villages) and Zaghouan (28 farmers from 3 villages).

Before the RCT started, a very few numbers of farmers had adopted Kounouz (the mean adoption rate in the total sample was below 1%). The farmers had access to the subsidy (33% seed price) in the first year of Mind the Gap project. Combined with the subsidy, the trainings offered to farmers have increased the adoption of Kounouz in the second year of project (Table 1).

Effectiveness of the randomisation implementation procedure: covariate balancing

The covariate balancing test was used to assess the effectiveness of the randomisation procedure in terms of delivering comparable groups (Dhehibi *et al.*, 2018). Results from this test, including descriptive statistics from the key sociodemographic variables used in the analysis, are shown in Table S2. To undertake this test, a balanced panel was used from household baseline data. We ensured that baseline characteristic variables were balanced for both control and the four treatment groups. According to Barrett and Carter (2010), this means no randomisation bias is detected. As a consequence, and following Ogutu *et al.* (2018), we can rely on difference-in-difference estimators for evaluating the treatment effects including a specific control for baseline differences in the regression model in order to overcome any potential existing randomisation bias.

Effects of attrition problem

The main evaluative strength of RCTs is that each group is generally balanced in all characteristics, with any imbalance occurring by chance. However, participants in many trials do not follow up the process properly. Such attrition prevents the full intended analysis of treatments being carried out and can introduce bias. Attrition can also occur when participants have missing data at one or more points.

In our case, the baseline survey included 700 farm household observations, but in the follow-up survey, we were only able to revisit 671 of these households. The average attrition rate was about 4.14%, with some variation across treatments and control groups (Table 2). Non-random attrition might bias the randomised design and subsequently the results. Data from the balanced panel (Table S2) suggest that attrition did not introduce significant randomisation bias (Ogutu *et al.*, 2018).

Estimation strategy

To measure the effect of the different extension treatments on farmers' adoption of *Kounouz*, a dummy variable was created. This took a value of1 if a household planted *Kounouz* during the

Table 2. Attrition rates across treatment and control groups

	Baseline number (%)	Follow-up number (%)	Attrition number (%)
Control	140 (25.00)	129 (19.22)	11 (7.85)
Treatment T1	140 (24.00)	137 (20.41)	3 (2.14)
Treatment T2	140 (25.00)	137 (20.41)	3 (2.14)
Treatment T3	140 (25.00)	137 (20.41)	3 (2.14)
Treatment T4	140 (25.00)	131 (19.52)	9 (6.42)
Observations	700 (100)	671(100)	29 (4.14)

Note: Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.

study period and 0 otherwise. To estimate the treatments effect on farmers' adoption, the following model was used, including only the observations of the follow-up survey:

$$Y_i = \beta_0 + \beta_1 T_1 + \beta_2 T_2 + \beta_3 T_3 + \ \beta_4 T_4 + \varepsilon_i \tag{1}$$

where Y_i is *Kounouz* adoption of farm household *i*, T_1, T_2, T_3 and T_4 are treatment dummies for the four treatment arms (T1–T4), β_1, β_2, β_3 and β_4 are the estimated treatment effects, and ϵ_i is a random error term clustered at farmer group level. Ordinary least squares was used to estimate equation (1). However, the cross-section model in equation (1) has several drawbacks, as it does not account for possible unobserved heterogeneity and non-zero adoption status at baseline. Therefore, we also developed and estimate difference-in-difference estimators using the baseline and follow-up data (Ogutu *et al.*, 2018).

When defining the treatment variables, the researcher must decide whether to estimate the intent to treat (ITT), the treatment on the treated (TOT) or both. The ITT estimates the average effect of offering the treatment on outcomes, or the effect on everyone who was offered a treatment, whether or not they received it. The TOT estimates the average effect of the actual treatment on outcomes, or the effect only on those who received the full treatment. In some cases where programme participation is voluntary, the ITT may be the more policy-relevant effect. In others, researchers may be interested in understanding the effect of the intervention on everyone in the population. In our case study, we estimate both ITT and TOT effects.

The difference-in-difference specification was used to estimate the ITT effects in the following equation:

$$Y_{it} = \beta_0 + \beta_1 Post_t + \beta_2 T_j + \beta_3 Post_3 \times T_j + \varepsilon_i \tag{2}$$

where Y_{it} is *Kounouz* adoption of household *i* in year *t*, $Post_t$ is a year dummy variable that takes a value of 1 for the follow-up data (collected in 2018/2019 cropping season) and 0 for the baseline data (collected in 2016/2017 cropping season), T_j is a dummy variable that takes a value of 1 if a farmer group is treated and 0 otherwise.

Treatments T1–T4 were estimated separately in this model, including the observations from the respective treatment group and the control group. Later, each of the treatment effects was only compared against the control group.

Parameter β_3 is of particular interest in equation (2), which is the difference-in-difference estimator of the ITT effect. This estimator overcomes possible selection bias from the absence of perfect balance in the baseline covariates and accounts for time-invariant unobserved heterogeneity and non-zero adoption status at baseline (Greene, 2012; Pamuk *et al.*, 2015; Ogutu *et al.*, 2018).

The model was extended in equation (2) to control for differences in baseline covariates as follows:

$$Y_{it} = \beta_0 + \beta_1 Post_t + \beta_2 T_j + \beta_3 Post_t \times T_j + \delta x_i + \varepsilon_i \tag{3}$$

where x_i is a vector of baseline socio-economic variables controls.

To estimate TOT effects, actual training attendance was used as a treatment variable and three specifications were considered (Ogutu *et al.*, 2018). In a first specification (TOT basic), training attendance was measured as a dummy variable that took a value of 1 if a household attended at least one of the training sessions offered in its group and 0 otherwise. In our case study, we do not observe perfect compliance in our RCT in terms of attendance rates for the four considered treatments (Table S3).

However, different training components were offered in T2, T3 and T4, and they were addressed in the second specification. In this second specification (TOT improved), the treatment variable for T2 was defined as a dummy that took a value of 1 if a household attended at least one technical and one economic and organisational training session and 0 otherwise. The treatment variable for T3 was defined as a dummy that took a value of 1 if a household attended at least one technical, one economic and organisational, and one female empowerment training session, and 0 otherwise. The treatment variable for T4 was defined as a dummy that took a value of 1 if a household attended at least one technical and one female empowerment training session, and 0 otherwise. In a third specification (TOT intensity), the intensity of training attendance was measured by the number of training sessions attended relative to all training sessions offered in the group (this treatment variable took values between 0 and 1).

The TOT effects were estimated using the following difference-in-difference specification:

$$Y_{it} = \beta_0 + \beta_1 Post_t + \beta_2 \hat{T}_j + \beta_3 Post_t \times \hat{T}_j + \varepsilon_i \tag{4}$$

where $\hat{T}_j$ is the fitted value of the treatment (actual training attendance) obtained from the first-stage regression with the instrument, $Post_t$ is a year dummy variable with a value of 1 for the follow-up data (collected in the 2018/2019 cropping season) and 0 for the baseline data (collected in the 2016/2017 cropping season), T_j is a dummy variable that took a value of 1 if a farmer group was treated and 0 otherwise.

To control the differences in baseline covariates, the model was extended in equation (4) as follows:

$$Y_{it} = \beta_0 + \beta_1 Post_t + \beta_2 \hat{T}_j + \beta_3 Post_t \times \hat{T}_j + \delta x_i + \varepsilon_i \tag{5}$$

Two-stage least squares estimator was used to estimate the models in equations (4) and (5). This estimator is widely used in econometrics to estimate parameters in systems of linear simultaneous equations and to solve problems of omitted variables bias in single-equation estimation (Angrist and Imbens, 1995). It also works efficiently and produces estimates with a robust causal interpretation for non-continuous treatment variables (Angrist, 2006; Ogutu *et al.*, 2018).

Results

Socio-economic profiles of the four considered treatments and control group

The socio-economic profiles of the four considered treatments and control group are slightly different for the main socio-economic variables except the farm productive assets (Table S4). The average age years fluctuates between 54.62 and 57.25 with a maximum and minimum of 95 and 21 in T1 and T3, respectively. As expected, the male household heads mainly responsible for the economic welfare of the household represented between 92 and 96% of the sample for all groups. Average number of years in education fluctuates between 3.36 years in T2 and 4.37 years for the control group. All the groups are composed by illiterate farmers without years of education and by farmers with high level of education (13 to 17 years). Average farm size ranges from 5.09 hectares in T2 to 6.56 hectares in T4. Regarding farm productive assets, the four treatments have an average value over than the control group especially T4 (7305.16 Tunisian Dinars against 2262.64. 1 Tunisian Dinar = US$ 0.44). These findings show the effectiveness of the randomisation procedure in terms of delivering comparable groups.

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Table 3. Effects of extension treatments on technology adoption, ITT estimates

Variables	Planted *Kounouz* (dummy) (1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1	0.239***(0.032)	0.239***(0.032)
Baseline controls	No	Yes
R-squared	0.110	0.118
Panel B: Treatment T2 (n = 532)		
Post × T2	0.114***(0.028)	0.114***(0.028)
Baseline controls	No	Yes
R-squared	0.055	0.059
Panel C: Treatment T3 (n = 532)		
Post × T3	0.362***(0.034)	0.363***(0.035)
Baseline controls	No	Yes
R-squared	0.192	0.207
Panel D: Treatment T4 (n = 520)		
Post × T4	0.263***(0.032)	0.277***(0.033)
Baseline controls	No	Yes
R-squared	0.128	0.142

*Notes: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

ITT effects on technology adoption

Table 3 presents the estimates of ITT effects for the decision to adopt *Kounouz* estimated with the difference-in-difference models explained in equations (2) and (3). Each treatment was compared only with the control group, and the estimates of ITT effects were done with and without baseline controls included. The ITT effects with and without baseline controls were identical for treatments T1 and T2 and almost the same for T3 and T4, indicating that difference-in-difference procedure controls for baseline difference were very pronounced.

The results showed the positive and significant effects of the four treatments on the likelihood of adopting *Kounouz*. This finding supports an effective role of the considered extension methods to increase the uptake of *Kounouz*. The effect on adoption of this technology differed among the four treatments. In Panel A, the estimates suggest that the farmers who were offered only technical training were 23.9 percentage points more likely to plant *Kounouz* than those in the control group (Table 3). For farmers who were offered the technical training and the economic and organisational training (Treatment T2 in Panel B), the likelihood of planting *Kounouz* was only 11.4 percentage points higher than those in the control group. This finding is unexpected and shows that there are some constraints related to the information diffused to the project farmers in treatment group 2. In this sense, the farmers who had attended economic and organisational sessions had very high expectations at the start of training and very low expectations at the end. In Panel C, the estimates imply that farmers who followed all training (technical, economic, organisational and female empowerment) were 36.2 percentage points more likely to plant *Kounouz* than those in the control group. Higher adoption of *Kounouz* in treatment T3 could be explained by the high training attendance rate and the inclusion of women's empowerment training. The female empowerment training had an impact on the adoption of *Kounouz*. This finding was confirmed by the farmers in treatment T4, who were offered technical training and female empowerment training, and for whom the likelihood of planting *Kounouz* was 26.3 percentage points higher compared to farmers in the control group.

Table 4. Effects of extension treatments on technology adoption, TOT basic estimates

	Planted *Kounouz* (dummy)	
Variables	(1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1	0.243***(0.043)	0.243***(0.043)
Baseline controls	No	Yes
R-squared	0.111	0.120
Panel B: Treatment T2 (n = 532)		
Post × T2	0.126***(0.040)	0.122***(0.041)
Baseline controls	No	Yes
R-squared	0.056	0.058
Panel C: Treatment T3 (n = 532)		
Post × T3	0.399***(0.040)	0.400***(0.040)
Baseline controls	No	Yes
R-squared	0.203	0.201
Panel D: Treatment T4 (n = 520)		
Post × T4	0.304***(0.044)	0.312***(0.312)
Baseline controls	No	Yes
R-squared	0.137	0.142

*Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

TOT effects on technology adoption

In this section, the TOT effects were estimated with the actual training attendance. In Table 4, the treatment variable was an attendance dummy that took a value of 1 if at least one of the sessions offered in the respective group was attended, and 0 otherwise. Results show that the farmers who were offered only technical training were 24.3 percentage points more likely to plant *Kounouz* than those in the control group. Furthermore, for farmers who attended technical, economic and organisational trainings, the likelihood of planting *Kounouz* was only 12.2 percentage points higher than for those in the control group according to the model with baseline controls. This finding implies that attending economic and organisational training in addition to technical training had a reducing effect (by half) on *Kounouz* adoption. This difference between treatments T1 and T2 was significant at $p < 0.01$. The economic and organisational trainings addressed to Treatment T2 decreased the adoption of *Kounouz* in ITT and TOT effects. This finding is related especially to the incomplete information given to the project farmers in terms of credit granting. In this sense, the failure of farmers who attended Treatment T2 to obtain credit from the banks (the certificates given by the trainers have not been accepted as a guaranteed document) had a negative effect on adoption of *Kounouz* in the second year of the project. This result shows how the quality of information given in the training sessions can encourage or discourage farmers from adopting a technology.

In contrast, farmers who attended all trainings were 40 percentage points more likely to adopt *Kounouz* than those that did not attend any training. In addition, *Kounouz* adoption rates for farmers who were offered technical and female empowerment trainings were 31.2 percentage points higher than those in the control group, according to the model with baseline controls. The TOT effects in Panels C and D imply that attending female empowerment training had an additional positive effect on adoption of *Kounouz*.

The TOT improved estimates were higher than the TOT basic estimates (Table 5). This means that for farmers who were offered the technical training, the likelihood of planting *Kounouz* was only 24.3 percentage points higher than for those in the control group according to the model with baseline controls. For farmers who attended the technical training and the economic and

Table 5. Effects of extension treatments on technology adoption, TOT improved estimates

	Planted *Kounouz* (dummy)	
Variables	(1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1	0.287***(0.028)	0.287***(0.028)
Baseline controls	No	Yes
R-squared	0.115	0.129
Panel B: Treatment T2 (n = 532)		
Post × T2	0.231***(0.055)	0.231***(0.055)
Baseline controls	No	Yes
R-squared	0.089	0.092
Panel C: Treatment T3 (n = 532)		
Post × T3	0.506***(0.051)	0.511***(0.051)
Baseline controls	No	Yes
R-squared	0.333	0.340
Panel D: Treatment T4 (n = 520)		
Post × T4	0.482***(0.033)	0.490***(0.034)
Baseline controls	No	Yes
R-squared	0.279	0.292

*Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

organisational training, the likelihood of planting *Kounouz* was 23.1 percentage points higher than those that did not attend any training. Comparing the TOT effects between treatmentsT1 and T2 suggests that participation in economic and organisational training reduced the *Kounouz* adoption rate, but this difference was non-significant ($p > 0.01$). The TOT improving effects of 55.1 percentage points for treatment T3 and of 49.0 percentage points for treatment T4 were higher than those for treatments T1 and T2. The results confirm the additional effect of the female empowerment training on *Kounouz* adoption.

In Table 6, the treatment variable was a continuous variable that measured the number of training sessions attended relative to all training sessions offered in the group. The TOT intensity estimates were higher than those of the improved TOT, especially for treatment T3. For farmers who were offered all types of training, the likelihood of planting *Kounouz* was 93.5 percentage points higher than for those in the control group according to the model with baseline controls. This group registered the highest attendance rate with about 94.9% of farmers attending any of the sessions offered by this treatment. This finding confirms the larger effects of the training modules, and the full conformity of farmers in attending training, on the adoption of *Kounouz*.

Heterogeneous treatment effects

In this section, ITT effects on *Kounouz* adoption are studied by gender and education of the head of household. Gender of the farmer has become an important socio-economic variable in understanding the adoption of agricultural innovative technologies. Ragasa *et al.* (2012) recorded a gender gap in adoption of agricultural technologies. Previous studies showed that gender negatively and significantly influences adoption of improved agricultural technologies (Mugonolaa *et al.*, 2013; Kassa *et al.*, 2014; Namonje-Kapembwa and Chapoto, 2016; Addison *et al.*, 2018). This is due to the unequal access to resource and information between women and men (Kabunga *et al.*, 2012; Mugonolaa *et al.*, 2013; Fisher and Kandiwa, 2014). Furthermore, Overfield and Fleming (2001) and Ogutu *et al.* (2018) found insignificant effects of gender on adoption.

The heterogeneous treatment effects by gender are shown in Table 7. Interactions between the treatment and gender dummies are significant and positive in Panels A–C, but significant and

Table 6. Effects of extension treatments on technology adoption, TOT intensity estimates

Variables	Planted *Kounouz* (dummy) (1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1	0.310***(0.050)	0.307***(0.051)
Baseline controls	No	Yes
R-squared	0.134	0.145
Panel B: Treatment T2 (n = 532)		
Post × T2	0.265***(0.069)	0.265***(0.069)
Baseline controls	No	Yes
R-squared	0.091	0.092
Panel C: Treatment T3 (n = 532)		
Post × T3	0.935***(0.065)	0.936***(0.065)
Baseline controls	No	Yes
R-squared	0.486	0.488
Panel D: Treatment T4 (n = 520)		
Post × T4	0.490***(0.071)	0.509***(0.072)
Baseline controls	No	Yes
R-squared	0.249	0.267

*Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

Table 7. Effects of extension treatments on technology adoption, ITT estimates by gender

Variables	Planted *Kounouz* (dummy) (1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1 × Male	0.037***(0.036)	0.203***(0.042)
Baseline controls	No	Yes
R-squared	0.185	0.194
Panel B: Treatment T2 (n = 532)		
Post × T2 × Male	0.267***(0.095)	0.329***(0.107)
Baseline controls	No	Yes
R-squared	0.060	0.064
Panel C: Treatment T3 (n = 532)		
Post × T3 × Male	0.200***(0.092)	0.229***(0.107)
Baseline controls	No	Yes
R-squared	0.196	0.213
Panel D: Treatment T4 (n = 520)		
Post × T4 × Male	−0.255***(0.088)	−0.221***(0.097)
Baseline controls	No	Yes
R-squared	0.136	0.154

*Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

negative in Panel D. This finding suggests that the female empowerment training combined with the technical training (treatment T4) had a positive effect on adoption of *Kounouz* for the female head of household in Panel D. This result implies the additional effect of female head of households on adoption of *Kounouz* when they attended training modules. Accordingly, decision-makers and extension services should make appropriate decisions on the timing and location

Table 8. Effects of extension treatments on *Kounouz* adoption, ITT estimates by education

	Planted *Kounouz* (dummy)	
Variables	(1)	(2)
Panel A: Treatment T1 (n = 532)		
Post × T1 × Education	0.037***(0.071)	0.050***(0.082)
Baseline controls	No	Yes
R-squared	0.163	0.175
Panel B: Treatment T2 (n = 532)		
Post × T2 × Education	−0.014***(0.040)	−0.011**(0.047)
Baseline controls	No	Yes
R-squared	0.056	0.059
Panel C: Treatment T3 (n = 532)		
Post × T3 × Education	−0.028***(0.048)	−0.018***(0.056)
Baseline controls	No	Yes
R-squared	0.192	0.209
Panel D: Treatment T4 (n = 520)		
Post × T4 × Education	−0.070***(0.044)	−0.065***(0.052)
Baseline controls	No	Yes
R-squared	0.134	0.153

*Note: Coefficient estimates are shown with robust standard errors clustered at farmer group level in parentheses. Baseline controls include age, gender, education, household size, farm size, value of productive assets and distance to market. *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels, respectively. Treatment T1, technical training; Treatment T2, technical training plus economic and organisational training; Treatment T3, technical training plus economic and organisational training plus female empowerment; Treatment T4, technical training plus female empowerment. Source: own elaboration from project field data, 2020.*

of training to ensure high attendance rates of female heads of households by not interfering with women's involvementin domestic activities (Addison *et al.*, 2018).

Education of farmers has been assumed to have a positive influence on farmers' decision to adopt modern technology insofar as it increases their ability to obtain, process and use information relevant to adoption of a new technology (Lavison, 2013; Namara *et al.*, 2013; Wainaina *et al.*, 2016). For education, a dummy variable was created that took a value of 1 if the farmer had at least 5 years of school education, and 0 otherwise. The results regarding heterogeneous treatment effects by education differed from usual expectations (Table 8). In fact, interactions between the treatment and education dummies were significant and positive in Panel A, but significant and negative in Panels B–D. These results suggest that technical training had an additional effect on adoption of *Kounouz* for farmers with high levels of education. Nevertheless, economic and organisational training and female empowerment training also had a low additional effect on adoption of *Kounouz* for farmers with low levels of education over and above agricultural training. This finding could be explained by the fact that most of the farmers involved in our RCT had a low level of education (less than 5 years of school education) and the training modules offered were personalised to these farmers. In this sense, Tunisian extension agents have used different methods and tools (e.g., posters, FBS and photos) to facilitate the understanding of farmers with low levels of education during the training modules.

Discussion

A few existing studies have employed RCTs and combined different types of training to promote the uptake of agricultural technology (Ogutu *et al.*, 2018; Yitayew *et al.*, 2021). This study adds to this existing research the female empowerment training component, which previous study did not. While our research results are specific to local context in Tunisia, the lessons learned are in line with these previous studies. In this sense, additional training helps farmers to better appreciate the technology's benefits and increases adoption.

Full compliance of farmers with training had larger effects on adoption of *Kounouz* than partial compliance in all treatment groups. In this sense, the likelihood of planting *Kounouz* by farmers who attended trainings compared to those who did not attend any session was multiplied by 1.26 for treatment T1, by 2.17 for Treatment T2, by 2.34 for treatment T3 and by 1.63 for treatment T4 by switching from TOT basic effects to TOT intensity effects. Furthermore, the share of households attending all trainings offered for the different treatments was very low (less than 7%). This is due to especially to the high opportunity costs of time and several other constraints (Fischer and Qaim, 2014; Ogutu *et al.*, 2018). This finding suggests adopting a new approach of technology transfer to motivate smallholder farmers to attend trainings, by particularly considering the time of the training, the compensation premium for poor farmers, the adapted technologies and the obstacles to women participating in agricultural training. These results are in line with previous studies in Tunisia (Dhraief *et al.*, 2019; Dhehibi *et al.*, 2020).

The additional economic and organisational training offered to farmers of Treatment T2 in addition to the technical training did not met the expectation that this could improve adoption of *Kounouz*. The observed low effect of the economic and organisational trainings can be explained by different factors. The main factor is related to the expectations of involved farmers regarding the outcome received from this training, which was very large at the start of training and very weak at the end. In addition, the short duration of the project activities did not allow meeting the objectives formulated at the start of the project. Finally, the small quantities of *Kounouz* sown (between 100 and 500 kg per farmer) did not permit changing the marketing strategy for most of the farmers.

The additional female empowerment training provided in two of the treatment groups of the RCT led to higher adoption rates of *Kounouz* over and above the effect of technical training for treatment T4 and the effects of technical training and economic and organisational training for treatment T3. This finding shows the importance of gender-sensitive extension programmes and their positive impacts on technology adoption of the household. Indeed, empowering women is beneficial for the choices and decision-making processes of the entire rural household. Male and female family members face different possibilities to access inputs and information and thus make technology adoption decisions differently (Gebre *et al.*, 2019). These decisions might be made jointly or separately depending on the individual, household or other conditions such as social norms and cultural dictates (Doss, 1999). Previous studies claimed that joint farm management positively influences technology adoption (e.g., Marenya *et al.*, 2015; Lambrecht *et al.*, 2016). In Tunisia, women's equality and protection are included in the country's new constitution. However, inequities persist, gender disparities in extension programmes endure and female farmers continue to be marginalised, having limited access to new information, practices and technologies. This study suggests that future agricultural extension programmes need to be inclusive in terms of gender to improve technology adoption, increase productivity and enhance income-generating opportunities for rural households.

Conclusion

In this research, we analysed how agricultural extension can be improved to increase the adoption of innovative agricultural technologies for the livestock–barley system in semiarid Tunisia using an improved barley variety as the innovation to be adopted. In particular, our ultimate goal was providing insights on how to cost-efficiently increase smallholder farmers' access to relevant agricultural services and to improve farmers' access to innovative technologies with specific focus on female farmers. Particularly, this study analysed whether technical training combined with economic and organisational training and female empowerment training increased the adoption of *Kounouz*. Results clearly showed the importance of trainings offered by the extension agents on adoption of *Kounouz* over 2 years for all treatments. Through the different combinations of improved access to inputs, technical information and/or economic and organisational information, according to the respective treatment groups, the female and male farmers were more likely to adopt *Kounouz*. The key hypothesis for this RCT study was that technical training combined with economic and organisational training and female empowerment training increases the uptake of technology adoption. A clear limitation of this approach is related to the fact that offering various training modules to female and male farmers is usually very expensive, in particular, the costs linked to the payment of specialised trainers and for logistics in rural areas. The main extension and development institutions in Tunisia suffer generally from a lack of financial and human resources to effectively organise training modules for farmers (Dhraief *et al.*, 2019). In this sense, a participatory method of training, including all key actors and at all levels, research, private and extension is strongly recommended to both improve the access of farmers to various trainings in a cost-effective way and for effective content delivery. The high costs resulted in a relatively small sample size in this study which lowered the statistical power. However, future research with larger samples and more training modules offered would require higher public budgets for extension, which may not be affordable. To reduce costs, we recommend conducting the training of farmers through both conventional (i.e., demonstration fields, economic training and organisational training) and non-conventional (information and communication technologies) methods given their cost-effectiveness. Special attention should be given to women because gender-sensitive training can enhance women's business skills so they can more effectively solve problems and become successful entrepreneurs.

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