FARM-LEVEL ADOPTION AND IMPACT OF AGRICULTURAL TECHNOLOGY: THE CASE OF RUSSIAN WHEAT APHID RESISTANT CULTIVARS IN SOUTH AFRICA[1]

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ABSTRACT

This paper emphasizes adoption and impact studies as tools to assess the benefits of agricultural technologies, and to provide feedback for further technology development. The findings are reported of a study undertaken to describe the adoption and impact of Russian wheat aphid (RWA) resistant cultivars developed by the South African Agricultural Research Council. The analyses employed farm-level data from surveys conducted in 1997 in the Central and Eastern Free State of South Africa. Rapid adoption of the cultivars was demonstrated since their first release in 1993. The area sown to the cultivars increased from 3% in 1993 to 46% in 1997. Correlation and multiple regression analyses suggested that adoption of the cultivars was influenced by the farmer's educational level, wheat area, and experience with RWA; the quality grades realized by resistant cultivars; and the combined weighted average yield of resistant and susceptible cultivars. Economic analyses using partial budgets indicated that resistant cultivars generated incremental net benefits ranging between 140 and 329 Rands/ha in 1997 prices. The findings demonstrate that various factors apart

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from pest resistance also influenced the farmers' decisions to adopt RWA resistant cultivars, and underline the importance of farm-level data in agricultural research and extension.

1. INTRODUCTION

This paper emphasizes adoption and impact studies as tools to assess the benefits of agricultural technologies, and to provide feedback for further technology development. Given the global decline in investments in agricultural research and extension, this information is increasingly required to assist decisions in resource allocation and priority setting. By responding to farmers' production conditions and experiences, agriculturalists can develop and recommend relevant and widely adopted technologies, and increase the impact of their initiatives. The paper reports the findings of a study that has been undertaken to describe the adoption and impact of Russian wheat aphid resistant cultivars developed by the South African Agricultural Research Council. The analyses employed data collected through surveys conducted in 1997 in the Central and Eastern Free State of South Africa. The factors affecting the farmers' adoption of the cultivars were assessed by correlation and multiple regression analyses, and the farm-level economic impact of the cultivars was estimated with partial budgets. We first outline the background to the study and methodology followed, before the results and conclusions are presented.

2. BACKGROUND TO THIS STUDY

The Russian wheat aphid (*Diuraphis noxia*) (RWA) was first reported in South Africa in 1978 (Walters, Penn, Du Toit, Botha, Aalbersberg, Hewitt, & Broodryk, 1980), and has been estimated to cause yield losses up to 92% (Walters, 1984, Tolmay & Wessels, 1996). Public sector research to address this problem was initiated at the ARC-Small Grain Institute (ARC-SGI) of the South African Agricultural Research Council. The program involved three stages of technology development, including chemical control, resistant cultivars, and biological control.

Research on chemical control started at the ARC-SGI in 1980 and culminated in appropriate control recommendations. However, apart from these recommendations, most chemical control technologies were developed by the private sector. The RWA can be chemically controlled by insecticides, which may be sprayed with tractors or airplanes, or applied as a seed treatment. The seed treatment was developed at a later stage and became available to farmers in 1993. Though chemical control provided a partial solution, it was considered expensive and harmful to humans and the environment.

Host plant resistance breeding for RWA commenced in 1985, and the ARC-SGI released the first resistant cultivar in the world in 1993, known as Tugela-DN. Private seed companies have also developed resistant cultivars since then. The ARC-SGI had released five and private seed companies eight of the thirteen resistant cultivars available to producers in 1996. Research on biological control of the RWA started in 1989 with the introduction of a natural enemy from Russia. This parasitoid (*Aphidius matricariae*) was released on a limited scale during 1996 and 1997, but biological control was still in its developmental stages at the time of this study.

The analyses presented in this paper focused on the technologies developed by the public sector, and focused on the RWA resistant cultivars released by the ARC-SGI. Appropriate data were not available to assess the impact of chemical and biological control, most chemical control technologies were developed by the private sector, and biological control was still under development.

3. METHODOLOGY

The analyses employed the results of farm-level surveys undertaken in 1997, in which data were collected on the farmers' wheat management practices in 1996. Data were collected through personal interviews using standard pre-tested questionnaires (Marasas, 1999). Information from a preliminary mail survey conducted in 1996 (Marasas, Anandajayasekeram, Tolmay, Martella, Purchase, & Prinsloo, 1997) was applied in compiling the questionnaires.

The study focused on the dryland summer wheat production areas of the Central and Eastern Free State of South Africa, where RWA occurred the most often. These two regions are separated according to climate and production considerations. A stratified random sample of ninety Central and Eastern Free State farmers was selected from the fourteen major relatively homogeneous farming areas in the two regions. A "relatively homogeneous farming area" has a fair degree of uniformity in agricultural use, attainable yields, and production practices. It consists of one or more land types, grouped together by taking into account the macro-climate, topography, geology, soil pattern, yield potential of resources, adapted crops, and vulnerability to wind and water erosion (Scheepers, Smit, & Ludick, 1984). The number of farmers from each major homogeneous farming area was selected by the respective areas under ploughable soil types suitable for wheat production. This aimed to represent the variability in wheat production conditions in the regions. The sampling frame consisted of producers' address lists obtained from institutions working in the area.

Farmers in the regions formerly known as Thaba Nchu and Qwa Qwa were also included in the study. Some climate and production considerations were similar in the Central Free State and Thaba Nchu; and the Eastern Free State and Qwa Qwa. However, Thaba Nchu and Qwa Qwa were not classified into homogeneous farming areas at the time. Since less information was available, and few farmers in these two regions have planted wheat in 1996, all farmers who could be contacted through the institutions working with them were interviewed. This included 20 producers, but the combined wheat area for the two regions comprised a relatively small proportion of the study area.

The survey results were separated for the Central Free State, Eastern Free State, Thaba Nchu, and Qwa Qwa, since the farmers' production conditions and wheat management practices differed. The factors affecting the producers' adoption of RWA resistant cultivars were assessed by correlation and multiple regression analyses, and the farm-level impact of the cultivars was assessed with partial budgets.

4. RESULTS AND DISCUSSION

Although regional differences were observed, the farmers' wheat management practices such as planting, fertilizer and herbicide application, and chemical control for pests and diseases other than RWA, did not differ significantly between RWA resistant and susceptible cultivars. The major differences between the two types of cultivars included the respective yield levels and the farmers' RWA control practices. These are outlined in the following two sections, and are pertinent to the adoption and impact analyses presented in sections

4.3 and 4.4. A detailed description of the farmer and farm characteristics, wheat management practices, and RWA control in the study area is provided in Marasas (1999).

4.1. Wheat yields of Russian wheat aphid resistant and susceptible cultivars

Yields varied between the numerous wheat cultivars planted in 1996, and pooled weighted average yields were calculated for resistant and susceptible cultivars, respectively (Table 1). Resistant cultivars demonstrated a weighted average yield advantage over the susceptible types, amounting to 0.15 tons/ha in the Eastern Free State, 0.25 tons/ha in the Central Free State, and 0.36 tons/ha in Thaba Nchu. Qwa Qwa was the exception where the weighted average yield of susceptible cultivars was higher. However, difficulties were experienced to obtain consistent yield estimates in this region due to problems with flooding and record-keeping by the farmers. This nevertheless comprised a minor proportion of the overall study area.

Table 1: Weighted average wheat yield in the study area (1996)

Region	**Weighted average yield (tons/ha)**	
	Resistant cultivars	**Susceptible cultivars**
Central Free State	**2.20**	**1.95**
Eastern Free State	**2.99**	**2.84**
Thaba Nchu	**1.47**	**1.11**
Qwa Qwa	**2.15**	**2.29**

4.2. Russian wheat aphid control practices

The ARC-SGI recommendations for RWA control comprised the use of resistant cultivars, or chemical control by either seed treatment or spraying for susceptible cultivars. However, the survey results demonstrated that the farmers used either no control, seed treatment, spraying, or both spraying and seed treatment; and that a proportion of resistant cultivars was also treated (Table 2). No Thaba Nchu farmers applied chemical control in 1996. Although spraying was continued on resistant cultivars in the remaining regions, only Eastern Free State producers continued seed treatment on these cultivars. Producers mostly combined the RWA insecticides with herbicides, fungicides, and other insecticides in the same spraying application, which reduced the application cost of spraying RWA insecticides. Although chemical control methods for RWA were still used in 1996, the farmers indicated a decline in their use since previous years, and projected further declining trends into the future.

Table 2: The percentage study area planted to resistant and susceptible cultivars, and treated with different options of Russian wheat aphid control (1996)

	Percentage area treated			
	No con-trol	**Sprayin g**	**Seed treat-ment**	**Spraying and seed treatment**
Central Free State:				
Resistant cultivars	85	15	-	
Susceptible cultivars	53	12	4	31
Eastern Free State:				
Resistant cultivars	45	5	28	22
Susceptible cultivars	5	14	55	26
Thaba Nchu:				
Resistant cultivars	100	-	-	-
Susceptible cultivars	100	-	-	-
Qwa Qwa:				
Resistant cultivars	70	30	-	-
Susceptible cultivars	43	23	34	-

Notes*: (-) indicates that the treatment was not used in the region. Estimates add to 100% across the rows of Table 2.*

4.3. Adoption of Russian wheat aphid resistant cultivars

The sample farmers rapidly adopted the RWA resistant cultivars developed by the ARC-SGI since their first release in 1993. The area sown to the cultivars increased from 3% in 1993 to 46% in 1997, and the farmers projected this area to increase further to 52% by the year 2000. In 1997, the area planted to the cultivars in each region was 68% in Qwa Qwa, 49% in the Eastern Free State, 41% in the Central Free State, and 35% in Thaba Nchu (Figure 1). The estimates exclude RWA resistant cultivars released by seed companies, since this study focused on the public sector investment in these cultivars. However, the survey results indicated that the ARC-SGI accounted for the major market share in RWA resistant cultivars over the period 1993 to 1997 (Marasas, 1999).

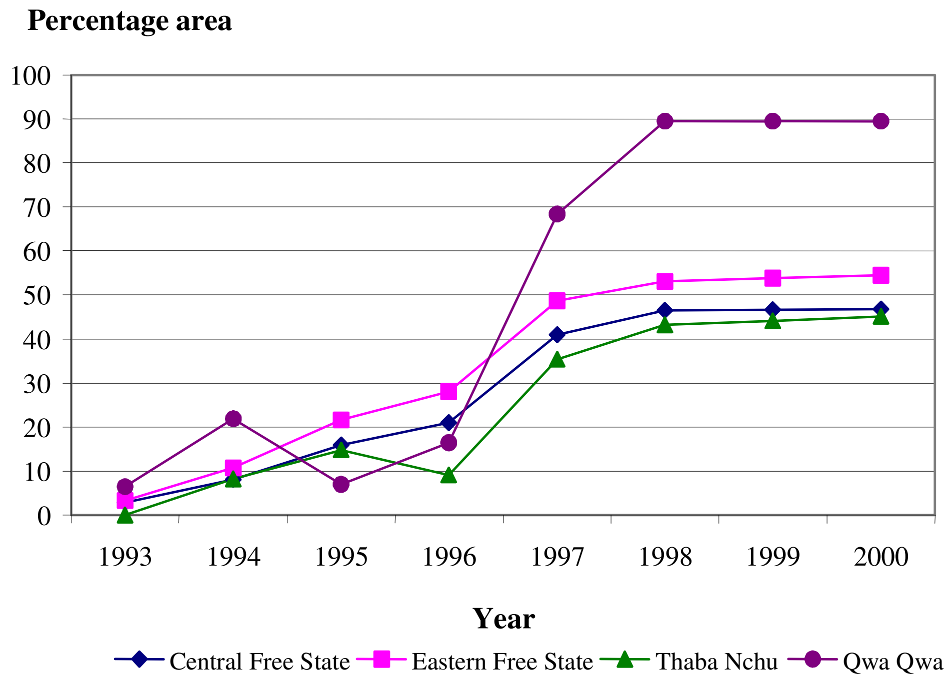

Figure 1: Adoption of Russian wheat aphid resistant cultivars released by the ARC-Small Grain Institute in the study area (1993 to 2000)

The factors affecting the farmers' adoption of RWA resistant cultivars were assessed by correlation and multiple regression analyses. The percentage area sown to the cultivars in 1996 was assumed as the dependent variable, and the analyses therefore described the behavior of adopters only. This included 73 of the 110 producers interviewed. All variables were converted to log values to improve the fit of the model. Pearson's correlation coefficients were used for continuous and Spearman's correlation coefficients for qualitative values. Several explanatory variables were initially considered, but not all of them significantly explained the farmers' adoption behavior (Marasas, 1999). Correlation was considered significant at the 5% level. The analyses were initially separated for the four farmer groups, but the regions as a variable did not significantly explain the producers' adoption decisions.

The farmer's educational level, wheat area, and the quality grades realized by resistant cultivars significantly explained adoption individually and in combination with other factors (Tables 3 and 4). The farmer's experience with the RWA was significant as an individual factor, while the combined weighted average yield of resistant and

Table 3: Correlation analysis of the factors significantly* explaining the adoption of Russian wheat aphid resistant cultivars in the study area (1996)[a]

Explanatory variables	Dependent variable (percentage area sown to resistant cultivars)		
	Correlation coefficients	Significance[b]	Explanation
Farmer's educational level	-0.23545	0.0449 (S)	Qualitative data coded for confirmation or denial that the farmer has studied at the tertiary level. Confirmation corresponds with a lower code value.
Farmer's wheat area	-0.24994	0.0330 (P)	Continuous variable.
Quality grades realized by resistant cultivars	-0.25722	0.0280 (S)	Qualitative data coded by the wheat quality grade realized. A higher wheat quality grade corresponds with a lower code value[c].
Farmer's experience with the Russian wheat aphid	-0.27339	0.0193 (S)	Qualitative data coded for confirmation or denial that the farmer has experienced Russian wheat aphid as a problem at any given time. Confirmation corresponds with a lower code value.

** Indicates statistical significance at the 5% level.*

[a] *Sample size (n) = 73 farmers.*

[b] *(P) denotes the Pearson's coefficients used for continuous data and (S) denotes the Spearman's coefficients used for qualitative data.*

[c] *The wheat quality grade classification effective in South Africa at the time is summarized in ARC-Small Grain Institute (1998) and Marasas (1999). Wheat quality is one of the major factors determining the wheat price received by farmers.*

susceptible cultivars was significant in association with other factors[1]. For the continuous variables, the dependent variable correlated positively with the combined weighted average yield of resistant and susceptible cultivars, but negatively with the farmer's wheat area. The interpretation of the correlation coefficients for the qualitative variables is explained in Table 3. The percentage area sown to resistant cultivars was higher when the farmer has studied at the tertiary level, experienced RWA as a problem at any given time, and when higher quality grades were realized by resistant cultivars.

Table 4: Multiple regression analysis of the factors significantly* explaining the adoption of Russian wheat aphid resistant cultivars in the study area (1996)[a]

Variables	T for H_O: Parameter = 0	Prob > |T|
Intercept	8.571	0.0001
Farmer's educational level	-2.392	0.0195
Farmer's wheat area	-3.113	0.0027
Quality grades realized by resistant cultivars	-2.251	0.0277
Combined weighted average yield of resistant and susceptible cultivars	2.268	0.0265

F value = 5.270; Prob>F = 0.0009; R-square = 0.2366; Adjusted R-square = 0.1917; and d.f. = 68.
** Indicates statistical significance at the 5% level.*
[a] Sample size (n) = 73 farmers.

The signs of the correlation coefficients were mostly in line with our expectations from the literature, except that the negative correlation of the farmer's wheat area with the percentage area sown to resistant cultivars initially seemed surprising. However, the survey results provided possible explanations for this finding. First, the producers in the study area planted various cultivars to spread their risk. Although the proportion of resistant to susceptible cultivars has increased substantially since 1993, this process of replacement may take longer over large wheat areas involving numerous cultivars. Second, if land could be assumed as a proxy for wealth, larger scale farmers might be less concerned about the costs of RWA control on susceptible cultivars, and might continue sowing larger proportions of susceptible cultivars for other desirable characteristics. Smaller scale farmers might be more concerned about the costs of chemical control, and might plant larger proportions of RWA resistant cultivars sooner. Third, large scale chemical control could be difficult to restrict to susceptible cultivars, and could render resistant cultivars less attractive over large areas planted to various cultivars. A fourth observation was that the average wheat area per respondent in 1996 was smaller in the regions where farmers have experienced more problems with RWA[1].

The results of the multiple regression analysis indicated that the factors affecting the farmers' adoption of RWA resistant cultivars in 1996 could be tentatively described as follows:

ln (Percentage area sown to resistant cultivars) = 5.48 - 0.81 ln (Farmer's educational level) - 0.33 ln (Farmer's wheat area) - 0.22 ln (Quality grades realized by resistant cultivars) + 0.61 ln (Combined weighted average yield of resistant and susceptible cultivars)

Though the relatively low R-square value of 0.24 in Table 4 initially caused some concern, it should be reasonable for cross-sectional farm-level data (Intriligator, 1978, International Maize and Wheat Improvement Center (CIMMYT), 1993, Bua, 1998, Marasas, 1999). Moreover, all variables included in the tentative model were significant, and the signs of the estimated coefficients were either as expected, or could be explained by observations from the survey results.

4.4. Farm-level impact

The farm-level impact of the resistant cultivars was estimated using partial budget methodology (see for example, CIMMYT, 1988). Since partial budgets involve only the production factors relevant to a specific investment decision, the analysis focused on the costs and prices differing between RWA resistant and susceptible cultivars. As demonstrated by the survey results, the major agronomic differences between the two types of cultivars were the respective yields (Table 1), and the farmers' RWA control practices (Table 2). Differences in wheat prices and seed costs were also included in the budgets.

Using producers' estimates obtained from the survey results, we calculated weighted average costs and prices, by area subjected to the various applicable management options used by the farmers, for resistant and susceptible cultivars respectively. We then calculated the respective net benefits of resistant and susceptible cultivars, and the incremental net benefits of resistant cultivars (Table 5).

Table 5: The farm-level incremental net benefits of changing from Russian wheat aphid susceptible to resistant cultivars (1997)

Options		Incremental net benefits (Rands/ha)	
Changing from	Changing to	Central Free State	Eastern Free State
Susceptible cultivars with no chemical control	Resistant cultivars with no chemical control	211	232
	Resistant cultivars with spraying	144	190
	Resistant cultivars with seed treatment	-	182
	Resistant cultivars with spraying and seed treatment	-	140
Susceptible cultivars with spraying	Resistant cultivars with no chemical control	267	280
	Resistant cultivars with spraying	200	238
	Resistant cultivars with seed treatment	-	230
	Resistant cultivars with spraying and seed treatment	-	188
Susceptible cultivars with seed treatment	Resistant cultivars with no chemical control	273	275
	Resistant cultivars with spraying	206	233
	Resistant cultivars with seed treatment	-	225
	Resistant cultivars with spraying and seed treatment	-	184
Susceptible cultivars with spraying and seed treatment	Resistant cultivars with no chemical control	329	323
	Resistant cultivars with spraying	262	282
	Resistant cultivars with seed treatment	-	274
	Resistant cultivars with spraying and seed treatment	-	232

Note: (-) indicates that the treatment was not used in the region.

Separate budgets were developed for the RWA control options shown in Table 2. The analysis focused on the Central and Eastern Free State, because Thaba Nchu producers did not use chemical control in 1996, and the lack of a demonstrable yield advantage precluded conclusive estimation of the incremental net benefits of RWA resistant cultivars in Qwa Qwa. Under the assumptions employed in this study, the farm-level incremental net benefits of RWA resistant cultivars ranged between 140 and 329 Rands/ha in 1997 prices. The benefits remained substantial for all alternatives considered in the analysis, even though chemical control was continued on a proportion of the resistant cultivars. This could be ascribed to the yield advantage of the cultivars. The findings suggest that the producers' continued use of chemical control on resistant cultivars was therefore not irrational, but might be explained by other considerations.

First, farmers indicated that they continued the practice as a perceived "extra precaution" to avoid RWA. This could be especially applicable to areas where farmers have experienced more problems with RWA. For example, 90% of Eastern Free State producers have perceived RWA as a problem at any given time[1], and these farmers also continued chemical control on RWA resistant cultivars to the largest extent (Table 2). Second, since the producers planted various resistant and susceptible cultivars, the logistics of large scale chemical control could be difficult to restrict to susceptible cultivars.

Nevertheless, the economic benefits of the resistant cultivars could improve if used without chemical control (Table 6).

Table 6: The farm-level incremental net benefits of changing from Russian wheat aphid resistant cultivars with chemical control to resistant cultivars without chemical control (1997)

Options		Incremental net benefits (Rands/ha)	
Changing from	**Changing to**	**Central Free State**	**Eastern Free State**
Resistant cultivars with spraying	Resistant cultivars with no chemical control	67	42
Resistant cultivars with seed treatment	Resistant cultivars with no chemical control	-	50
Resistant cultivars with spraying and seed treatment	Resistant cultivars with no chemical control	-	91

Note: (-) indicates that the treatment was not used in the region.

Potential incremental net benefits ranging between 42 and 91 Rands/ha could be realized. Technology transfer efforts should therefore encourage producers to discontinue chemical control on resistant cultivars in order to reap their full economic benefits.

5. CONCLUSIONS

This paper demonstrates the farm-level adoption and impact of RWA resistant cultivars developed by the South African Agricultural Research Council. The analyses employed data from surveys conducted in the Central and Eastern Free State of South Africa in 1997, and showed that the cultivars were rapidly adopted since their first release in 1993. The area sown to the cultivars increased from 3% in 1993 to 46% in 1997, and producers projected this area to increase further to 52% by the year 2000. However, the survey results demonstrated that the farmers' use of RWA resistant cultivars deviated from the recommendations by the ARC-SGI, since chemical control was continued on a proportion of the cultivars.

Correlation and multiple regression analyses suggested that adoption of the cultivars was influenced by the farmer's educational level, wheat area, and experience with the RWA; the quality grades realized by resistant cultivars; and the combined weighted average yield of resistant and susceptible cultivars. Partial budget analyses indicated that the resistant cultivars generated incremental net benefits ranging between 140 and 329 Rands/ha in 1997 prices, even though chemical control was continued on a proportion of the cultivars. This could be ascribed to the yield advantage of the cultivars.

Thus, various factors apart from pest resistance alone also influenced the farmers' decisions to adopt RWA resistant cultivars. This emphasizes that agricultural technologies are often of an integrated nature, and innovations such as germplasm improvement for pest resistance can therefore not be developed in isolation from other considerations. The paper focuses on the farm-level adoption and impact of the RWA resistant cultivars, but other positive economic, environmental, institutional, and spill-over impacts were also associated with the cultivars (Marasas, 1999).

The results of this study underline the importance of adoption and impact studies as tools to assess the benefits of agricultural technologies, and to provide feedback and insight into producers' decision-making behavior. Farm-level data enable agriculturalists to evaluate the impact of their efforts, and to refine experimental results and the recommendations released to producers. Increased emphasis on adoption and impact studies is likely in view of the globally declining investments in agricultural research and extension, and greater demands for accountability.

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NOTES

[1] Further descriptive survey information regarding the factors significantly explaining the farmers' adoption behavior in 1996 include:

Farmer's educational level: Fifty two percent of the Central and Eastern Free State producers studied at the tertiary level, and 27% of them had studied agriculture specifically. No Qwa Qwa farmers and only one Thaba Nchu farmer obtained tertiary training, in a discipline other than agriculture.

Farmer's wheat area: The average wheat area per respondent was 463 ha in the Central Free State and 418 ha in the Eastern Free State, and the producers managed anywhere from one to 15 farms. The average wheat area per respondent was 37 ha in Thaba Nchu and 55 ha in Qwa Qwa, and the producers managed one to four farms.

Quality grades realized by resistant cultivars: Sixty eight percent of the area planted to resistant cultivars in the Central and Eastern Free State realized BPS and BP1 grades. According to the wheat quality grade classification effective in South Africa at the time, BPS and BP1 represented the grades with the highest associated prices (ARC-SGI, 1998, Marasas, 1999).

Farmer's experience of the aphid: The RWA has been perceived as a problem at any given time by 90% of Eastern Free State, 68% of Central Free State, 46% of Thaba Nchu, and 43% of Qwa Qwa farmers.

Weighted average wheat yields of resistant and susceptible cultivars: Described in Section 4.1 and Table 1. Weighted average yield levels were the highest in the Eastern Free State.

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