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Economic Returns of public research and development funding in South Africa: Evidence from the Agricultural Research Council's table grapes cultivar development programme

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The study sought to estimate the genetic gains and associated monetary value contributed by the TGCD programme of the Agricultural Research Council (ARC). The Just-Pope production function and cost benefit analysis (benefit cost ratio – BCR, and modified internal rate of return – MIRR) were employed to analyze the administrative programme costs and industry yield data for the ARC's cultivars. The results revealed an average annual yield gain of 0.21 t/ha for the period from 1965 to 2014, and a BCR of 4.85. An MIRR of 18% was also revealed. This means that for every rand invested in the programme, R4.85 is realized and the high MIRR further confirms the worthiness of these investments. Thus, these results are useful as evidence for the missing information on the effectiveness and efficiency of public funds expended in table grapes research and as motivation for increased funding, as well as for participation by other industry stakeholders.

Keywords: ARC, cost benefit analysis, economic returns, just-pope production function, table grapes

Introduction

The South African table grape industry contributes towards important national objectives such as employment creation, foreign currency earnings and farm income generation. As such, it features among most labour-intensive industries that are prioritized in national imperatives, such as the National Development Plan (National Planning Commission – NPC 2011). Grapes are grown for several reasons in South Africa, such as for consumption, fresh, as table grapes, for processing into jams and jellies, for drying as raisins, and for wine production (Department of Agriculture Forestry Fisheries – DAFF 2012). Grapes grown for table grapes and dried grapes encompassed 32% of the total area allocated to deciduous fruits in 2017 (HORTGRO 2017). The expansion of the industry has meant more jobs, foreign revenue generation and income for farmers (DAFF 2016).

With reference to job creation, employment in the table grape industry has gained strength over time, from a total of 10,628 permanently employed workers in 2011 to a total of 14,796 workers in 2016 (DAFF 2016). South Africa is export orientated, as it exports approximately 80% of its table grape produce (DAFF 2012; Food Agriculture Organization – FAO 2016). Moreover, South Africa ranked number six in world exports in 2016 (FAO 2016). The foreign revenue earnings generated from the table grape industry in South Africa were expected to increase by R2.5 billion after an amendment of rules in 2016 regarding shipment of table grapes from South Africa to China, from below freezing to higher temperatures, which resulted in an increased opportunity for market expansion.

Research and development (R&D) is among the factors contributing to the success of the table grape industry. Innovations facilitate and keep the table grape industry competitive enough to meet the needs of consumers (Burger et al. 2010; South African Table Grape Industry – SATI 2017). R&D also has a history of enhancing productivity. In South Africa, most public agricultural research is conducted through the Agricultural Research Council (ARC) for the advancement of the agricultural sector and other related industries (ARC 2016). Therefore, the following research endeavours within the ARC's R&D space seek to advance the table grape industry: Cultivar Development; Natural Resource Management; Crop Production; Disease Management; Pest Management; and Post-harvest Management (SATI 2017).

The focus of attention in this paper is the TGCD programme, which has experienced tight budget allocations over the past five years due to increased competition among research activities. This breeding programme for new table grape varieties is undertaken by the viticulture division and has three separate projects that run concurrently: breeding of new table grape cultivars using conventional breeding methods; breeding of seedless grapes by embryo rescue; and evaluation and screening of new table grape selections and cultivars. The programme depends mainly on funding apportioned through the Parliamentary Grant allocated to the ARC, and partially on complementary funding from SATI. The TGCD programme of the ARC has successfully bred a total of 37 cultivars (25 seedless and 12 seeded) since its establishment in 1952. Changed dynamics in breeding have been experienced, where the last decade (2008–2018) has seen a release of only seedless table grape varieties – about six varieties (Burger et al. 2010).

Nevertheless, public research funding continues to pose a major constraint towards the realization of R&D objectives, because of limited public funds (Vink 2000). The ARC Parliamentary Grant was cut by R233 million over the Medium Term Expenditure Framework (MTEF) period of 2014/2015–2016/2017. While the first cut of R40 million was implemented in the financial year 2014/2015, the second cut took effect in 2015/2016 (ARC 2016). The limited public funding of R&D has been a main motive prompting resource use efficiency and effectiveness studies (Anandajayasekeram and Martella 2000). Therefore, increasing efforts to account for the value of money expended in the agricultural research and development space are imperative. Townsend and van Zyl (1998) argue that such endeavours are not only justifiable at national level, but also at crop level and beyond.

In response to the call by Townsend and van Zyl (1998), a rise in the number of studies attempting to account for the value of money in science at sectoral level and beyond was recorded in the past decade. Tsvakirai, Liebenberg, and Kirsten (2018) used an Almond Polynomial lag distributed model and estimated the eturns to peach- and nectarine-related research and development investments to be 55%. In a similar study on beef, a marginal rate of return of 32% was found to be associated with the improvement scheme (Nevondo et al. 2019).

Various studies have estimated the yield gains associated with varietal improvements (e.g., Dlamini et al. 2017; Nalley, Barkley, and Featherstone 2010; Nhemachena, Kirsten, and Liebenberg 2019). Normally, the costs do not enter directly into the model but use years dummies, while account for the lead and lag time, for identification of the impact on yield gains. Nhemachena, Kirsten, and Liebenberg (2019), employing a vintage regression model, estimated the yield gain from dryland wheat varietal improvements grown in winter and summer to be 0.84% per year (19.84 kg/ha/year) and 0.5%, respectively. Moreover, both irrigated winter and summer wheat varietal improvements were found to be associated with the same yield gains (16.65 kg/ha/year). Nevertheless, the estimation models of Dlamini et al. (2017) regarding the augmentation of yield gains offer more insight because they provide allowance for an estimation of efficiency measures such as the BCR and IRR in the second stage of the analysis.

These studies are useful providers of relevant procedures and indicators of genetic improvements for use in the present study. Moreover, they show that the results of R&D investment have so far been associated with positive and high returns. However, this seems to have not influenced the flow of further investment into agricultural research and development. Instead, agricultural programmes have continued to receive budget cuts. Researchers attribute this negative occurrence to the long lead-time periods with which R&D investments are normally associated.

Although the literature on economic returns to R&D investment abounds, there are few studies that have evaluated the impact of breeding programmes on genetic gains of horticultural crops. Townsend and van Zyl (1998) only evaluated the economic contribution of wine grapes research in South Africa. No studies have been found that estimate investment returns related to breeding impacts on table grape yield gains. Specifically, the effects of the ARC's TGCD programme on yield gains have not been established. Therefore, the aim of the present study is to estimate the economic returns associated with the ARC's TGCD programme, with specific focus on the genetic gains and associated monetary value. Moreover, the study will determine the risk associated with genetical improvements, since the Just-Pope production function allows for the tracking of changes in variance over time. The evidence of returns on R&D related to table grapes generated in the study is important because it not only offers insight into the yield gains associated with the programme, but also sheds light on the efficiency of the programme.

Methods and procedures

Data

The ARC has released 37 table grape cultivar varieties since the establishment of its TGCD programme in 1952. As such, the following data on each cultivar was solicited from the ARC Infruitec-Nietvoorbij Institute, SATI and Culdevco:[1] type of variety (Seeded or Seedless), release year, and actual producer yields. The data covered the period from 1965 to 2014, which marks the times of release of the first and the last ARC cultivar variety, respectively.

Other data (obtained from the Abstract of Agricultural Statistics, SATI and ARC) are comprised of annual table grapes prices, adoption rates for ARC varieties, fixed and annual cost of running the breeding programme for BCR, and MIRR estimation. The annual average prices of table grapes and the costs of running the breeding programme were adjusted for inflation by using a Consumer Price Index (CPI) obtained from the International Monetary Fund (IMF). The study used annual average interest rates on deposits, solicited from the IMF, as proxies for discount rate for calculations of discounted benefits and costs.

Contextualization of data

Previous studies used experimental yields to estimate returns to grain crops breeding research. According to Dlamini et al. (2017), an implicit assumption exists with regard to the use of experimental yields. Accordingly, the assumption is that actual yields from producers are equal to yields from test plots. Annual changes in relative yields are measured by using performance test data, which reflect ideal management and agronomic practices, rather than actual grain crop performance yields. In this regard, Dlamini et al. (2017) acknowledge the existing difference between experimental and actual yields and put forward the argument that variety trials are the only reliable sources of relative yields. This means that the absolute yield/yield variance could be higher/lower in test plots, but the relative difference should be the same between test plots and actual producer yields. Nevertheless, quality improvements have also been found to be an important contributor to the adoption of modern crop varieties. As such, Brennan (1989) argues that little consideration had been given to quality adjustments in studies estimating returns to grain crop breeding programmes.

In this context of table grapes, the unavailability of applicable data limited the use of experimental yields; hence, the use of data on actual producer yields. The use and manipulation of actual producer yields followed from the motivation provided above. Townsend and van

Zyl (1998) argue that inadequacies in time series and specific project data should not be taken lightly because these prevent rigorous economic analysis being undertaken. The fact that absolute yield/yield variance could be higher/lower in test plots, while the relative difference should be the same between test plots and actual producer yields, once again justifies the use of actual aggregate producer yields. The quality of table grape yields is the most important factor in the breeding of new table grapes. Important considerations are given to the characteristics of table grapes, such as loose and crunch berries, texture, and size of berries, when decisions about the release of a new cultivar are made. It is, therefore, of little significance for a table grape breeder to give much attention to the quantity of yields per hectare, let alone to collecting experimental yield data, as grapes often need to have their berries pruned, a yield-reducing activity, for purposes relating to quality enhancement.

Adjusting for quality is always beneficial in horticultural research. Townsend and van Zyl (1998) estimated returns to wine grapes research by using both quality adjusted and quality unadjusted yields and obtained results that varied considerably. In their analysis, they made an important assumption that prices reflect the quality of a final product. A ratio of the Gross Value of Production (GVP) of each cultivar variety to the GVP of all grapes, normalized to one in 2010 prices, was constructed to account for quality, a major breeding objective in horticulture. As postulated by Townsend and van Zyl (1998), changes in this ratio reflect quality changes. For example, an increase in this ratio reflects increases in quality and vice versa. Hence, a product of this ratio and yields was formed for the purpose of adjusting for quality.

Thus, this study only used quality-adjusted yields because the approach of accounting for quality improvements proves to be strikingly relevant in horticultural research, particularly grape breeding research. The results associated with quality-unadjusted yields are also provided in the appendix (Table A2). Moreover, actual producer yields per hectare, made available by CULDEVCO and SATI, are used in calculating GVP (GVP = yield multiplied by price).

The quality-adjusted yields have significant variations, compared with unadjusted yields (Figure 1). For example, table grape variety number seven (Ronelle) shows high yields when quality is taken into consideration, as compared with the quality unadjusted yields for Ronelle (Figure 1).

The difficulty of isolating or separating the benefits associated with breeding programmes from other yield enhancing factors has been an issue in the literature of economic returns. In the context of table grape production, the difficulty would be to separate the TGCD programme's contribution from that of other factors such as improvement in managerial ability and improvement in viticultural practices. Nevertheless, econometric methods have lent themselves as a solution.

Econometric methods have been regularly used since their introduction by Cobb and Douglas, who attempted to fit manufacturing data into a model of output, labour and capital. Considerable developments have been made since the introduction of the model. Currently, several other models exist that are extensions of the Cobb–Douglas production function, and the Just-Pope production function is one of them.

The Just-Pope production function

The Just-Pope was constructed under the assumption that certain factors not only influence the mean of the output, but also influence the variance of the output. In the context of table grape breeding, cultivar development programmes are not only expected to increase yields, but also to reduce risk (variance). Thus, the Just-Pope becomes a corollary of the general Cobb–Douglas production function because of the assessment of the variance-influencing factors (Just and Pope 1978).

It has gained popularity in modelling yield gains associated with breeding programmes. Nalley, Barkley, and Featherstone (2010) used it to estimate genetic and economic impacts of a wheat-breeding programme for local producers in Yaqui Valley, Sonora, Mexico. Dlamini et al. (2017) also used the Just-Pope to estimate returns to the dry beans breeding programme of the ARC. Therefore, the Just-Pope production function was adopted for this study, due to its relevance. Moreover, it best fitted the data that was used in this study to estimate yield gains and changes in yield variance associated with the ARC's TGCD programme, and provided the best estimates when compared with other functions such as the Ordinary Least Squares (OLS).

There are several other benefits associated with the Just-Pope production function. It circumvents collinearity problems that are encountered when the Cobb–Douglas production function is used. The inclusion of highly correlated investment terms in Cobb–Douglas requires estimating lag length and determining lag structure to solve this problem (Schimmelpfennig et al. 2000; Townsend and van Zyl 1998). Moreover, the multiplicity of breeding objectives associated with breeding programmes causes heteroscedastic error terms to arise. However, the Just-Pope has a built-in solution for such a problem and deals with it right away.

Empirical model estimation

The mean and variance of output were modelled as follows:

$$Y_{it} = \beta_0 + \beta_1 RLYR_{it} + B_2 L_{it} + \varepsilon_{it} \tag{1}$$

$$ln\ (\hat{e}_{it})^2 = \beta_0 + \beta_1 RLYR_{it} + B_2 L_{it} + \ \varepsilon_{it} \tag{2}$$

where Y_{it} and $(\hat{e}_{it})^2$ are the mean and the variance of output, respectively; $lnRLYR_{it}$ is the release year of each variety; $L_{it}$is a dummy variable *(seedless or not)*; β_i, represents parameter vectors to be estimated; and ε_{it} is the conventional error term.

The release year variable can be construed as the 'vintage' of a breeding technology (Arrow 1962; Dlamini et al. 2017; Nalley, Barkley, and Featherstone 2010; Traxler et al. 1995). The coefficient on the RLYR

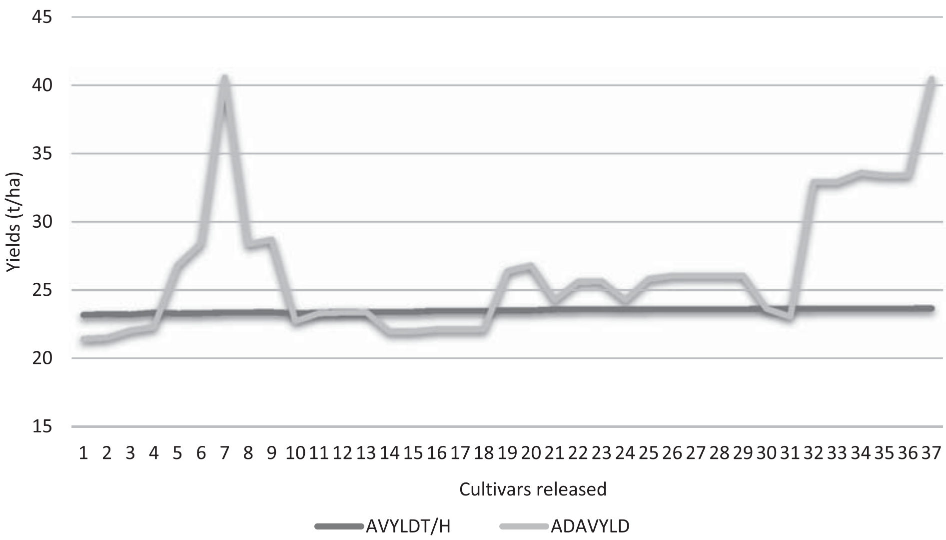

Figure 1: Thirty-seven cultivars released by the ARC since 1965 and their respective adjusted and unadjusted potential yields in tons per hectare.
Source: Constructed with the data obtained from ARC, CULDEVCO, SATI and DAFF

(β_1) measures the impact (on yield and yield variance) of the breeding programme (in this case the TGCD Programme). This is because it captures the progression of the breeding technology over time. For each variety, there is a single release year – the date of release of each cultivar to the general public for commercialization – and each cultivar released has a breeding technology for that particular year incorporated in it.

Thus, in estimation of the multiple regression model, the effect of the technology in the newly released table grape cultivar was captured by the coefficient of the RLYR. According to Nalley, Barkley, and Featherstone (2010), a variety's life cycle is assumed to exist as long as the cultivar is higher yielding than its predecessors were, and continues until relatively higher yielding successors are released. RLYR does not represent a time-trend variable, but is viewed in the same way that Arrow's (1962) growth model embodied technology in capital (Dlamini et al. 2017). Accordingly, Nalley, Barkley, and Featherstone (2010) argue that this method has been standardized to measure the impacts of advances in technology on output. Ideally, a dummy variable for type of variety of table grape (i.e., 1 if the variable is seedless and 0 if otherwise) is included to capture inherent differences across table grape species.

Estimation of cumulative benefits and costs

To calculate cumulative genetic gains, the coefficient of RLYR from the Just-Pope production function was multiplied by the number of years under investigation (Mazwane 2019). According to Nalley, Barkley, and Featherstone (2010), it is important to calculate the genetic gains associated with a breeding programme. This is done by taking into account the cumulative effects of the programme over the entire period. For example, yield gains that can be attributed to the breeding programme in 2017 are those observed in that year and the previous year (2016). Therefore, the genetic gains associated with the ARC's TGCD in 2016 would be the sum of the year-specific genetic gains from 1965 to 2016.

The economic benefits for producers of South African table grapes are represented by a function of a number of factors that are exogenous to the breeding programme (acreage, price, adoption rate, etc.) and an endogenous factor, the genetic gains derived from the ARC breeding programme. Therefore, the cumulative economic gains for the entire period under investigation from the ARC breeding programme were calculated as follows:

$$A_{ARCt} = A_{Tt} \times \emptyset_t \tag{3}$$

where A_{ARCt} is the area planted only to ARC cultivars in South Africa in year t, A_{Tt} is the total area planted to table grapes in South Africa in year t, and $\emptyset_t$ is the adoption rate of ARC varieties in year t.

The additional production from the ARC varieties was estimated using the following equation:

$$Y_{ARCt} = A_{ARCt} \times \beta \tag{4}$$

where Y_{ARCt} is the additional production from ARC in year t, A_{ARCt} is the area planted only to ARC cultivars in South Africa in year t (Equation 3), and β is the cumulative genetic gains in year t.

Economic gains derived from the ARC varieties were estimated using the following equation:

$$R_{ARCt} = Y_{ARCt} \times P_t \tag{5}$$

where R_{ARCt} is the cumulative economic gains from ARC's TGCD programme in rand in year t, Y_{ARCt} is the additional production from ARC in year t, and P_t is the price of table grapes in year t for all the years under consideration.

Cost–benefit analysis of the TGCD programme

The Cost–Benefit Analysis was undertaken to ascertain the net benefits of the cultivar development programme. The annual cost data and estimated annual benefits were discounted to 2010 rand values to account for the time value of money. The deposit interest rate for government funds (obtained from the IMF) was used as a proxy for a discount rate. This also takes into consideration the 12-year lag that exists between the initial cross and the release year. Moreover, to gauge research efficiency, the Modified Internal Rate of Return (MIRR) was estimated. Kierulff (2008) defines MIRR as the discount rate that renders the present value of the opportunity equal to that of the investment. In other words, it is the discount rate that renders the value of NPV equal to zero. Accordingly, the following formula was used for BCR estimation:

$$BCR = \left[\frac{B_0}{(1+i)^0} + \ldots + \frac{B_0}{(1+i)^T}\right] / \left[\frac{C_0}{(1+i)^0} \cdots + \frac{C_T}{(1+i)^T}\right] \quad (6)$$

As a rule of thumb, a BCR greater than 1 suggests that the TGCD Programme is worth the investment.

Several studies have estimated high IRRs for agricultural research, and this has raised concerns (Dlamini et al. 2017). As such, the MIRR was considered to be appropriate for this study. The MIRR is a better measure because it solves three major drawbacks associated with the IRR calculation (Kierulff 2008). Firstly, multiple solutions are likely to arise with the traditional IRR when cash flows fluctuate from negative to positive more than once. Secondly, the IRR assumes that positive cash flows are reinvested into the project at the IRR, and the conformity of this assumption with reality is a major concern. Thirdly, there are difficulties in ranking mutually exclusive projects when they have different lifespans and are not equal in sizes. Accordingly, the study is once again justified in using the MIRR for calculation of reliable rate of returns estimates for the TGCD Programme. The following formula was used to estimate the MIRR:

$$MIRR = \sqrt[n]{\frac{FVCF(c)}{PVCF(c)}} - 1 \quad (7)$$

where $FVCF(c)$ is the future value of positive cash flows at the cost of capital, $PVCF(c)$ is the present value of negative cash flows, also at the cost of capital, and n is the number of periods. The IRR and MIRR share a rule of thumb. In this regard, the project is attractive when the MIRR is greater than the discount rate. The MIRR that exceeds the discount rate signals a worthwhile opportunity for investment.

Results and discussion

Regression results

Table 1 shows the results of the Just-Pope production function, including the effects of new varieties on yield and yield variances, as well as estimates of the Ordinary Least Squares for comparisons. The Just-Pope model (Table 1, 'Just-Pope yield') had the largest coefficient of determination (R^2), suggesting that 58% of the mean yield is accounted for by the explanatory variables included in the model. This is a large R-squared relative to values obtained by other studies of this nature. For example, Dlamini et al. (2017) obtained an R^2 of 24% when estimating the impact on yield gains of breeding new dry bean varieties.

The variable RLYR was the variable of interest because it captures the 'vintage' (i.e., the level of technology incorporated in each table grape variety). Accordingly, after a transformation of the variable RLYR from the Just-Pope model into annual average gains, the results showed that the ARC's TGCD had an annual marginal effect of 0.21 t/ha ($P < 0.001$) in table grape yields from 1965 (with the release of Muska) to 2014 (with the release of Joybells), holding other factors constant (Table 1). This means that the average yields of ARC varieties increase by 0.21 t/ha (210 kg/ha) when there is a release of a new cultivar variety by the ARC's TGCD programme, *ceteris paribus*. Since the average yield of ARC table grape varieties for the period from 1965 to 2014 was 26.5 t/ha, this reveals an annual yield of 0.21 t/ha or 0.79% (0.21/26.5) that is directly attributable to the ARC's TGCD programme.

These estimates are comparable with those found in similar studies. Nalley, Barkley, and Featherstone (2010) and Dlamini et al. (2017) found the annual yield gains linked to Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and dry beans breeding research programme to be 0.46% and 1.06%, respectively. In a similar study on wheat, Nhemachena, Kirsten, and Liebenberg (2019) found varietal improvements for wheat grown in winter and summer to be 0.84% per year and 0.50%, respectively. Thus, the estimates of the present study are considerable when taken together with those of similar

Table 1: Regression results of adjusted for quality yields from the ordinary least squares (OLS) and Just-Pope production functions.

Variable	OLS yield	Just-Pope yield	Just-Pope variance
Intercept	−275.81	−396.24	−72.46
	(146.44)**	(119.27)***	(60.83)
RLYR	0.15	0.21	0.037
	(0.073)**	(0.060)***	(0.03)
Seeded	−2.48	−2.13	−0.39
	(1.95)	(1.17)*	(0.81)
Adjusted R^2	0.29	0.58	0.062

Notes: Significance levels are as follows $^*P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$. RLYR, release year

Table 2: Per hectare cumulative genetic gains associated with the Agricultural Research Council TGCD Programme, 2008–2017.

Year	Cumulative genetic gain (t/ha)	Additional production from 7 ARC varieties (t)	Real price(R/t)	Economic gains (R/year)	Discounted economic benefits (R/year)	Discounted costs (R/year)
Initial investment (R)						196,125,649
2008	9,03	27,058	7,456	201,763,295	188,632,434	2,865,026
2009	9,24	23,890	7,244	173,082,015	151,286,563	2,738,762
2010	9,45	25,837	7,600	196,368,272	160,470,032	2,620,473
2011	9,66	18,096	7,557	136,769,399	104,492,656	2,566,174
2012	9,87	19,076	8,227	156,951,306	112,107,836	2,496,202
2013	10,08	16,247	9,027	146,673,102	97,948,033	2,401,782
2014	10,29	15,761	9,144	144,136,297	89,989,701	2,224,878
2015	10,5	12,175	9,487	115,511,495	67,424,675	2,161,223
2016	10,71	9,741	9,478	92,338,014	50,390,468	1,671,899
2017	10,92	8,090	9,696	78,446,438	40,023,521	1,477,434
Average				144,203,963	1,062,765,923	219,349,506
BCR = 4,85						
MIRR = 18%						

studies, but can be regarded as moderate when placed against them, as they fall somewhere in the middle.

The cumulative contribution for the period under consideration can be easily computed by multiplying the annual yield gains of 0.21 tons/ha/ by the number of years (52) that the programme has been in existence from 1965, up to 2017. Cumulatively, the ARC's TGCD programme has contributed 10.92 t/ha over the same period. This is equivalent to a 41.2% (10.92/26.5) increase in actual table grape yields (Table 2) for the same period. This large contribution supports the hypothesis made earlier that there is a proportion of the mean yield increases that is directly attributable to the ARC's TGCD Programme.

With reference to the Just-Pope yield variance, the varieties released by the ARC's TGCD Programme since 1965 did not lead to an increase in the yield variance ($P > 0.1$) (Table 1), *ceteris paribus*. This means that, although the TGCD programme continues to increase the table grape average yields, variance that signifies risk changes is not affected. This is in line with the findings of Dlamini et al. (2017) who ascertained that efforts to raise the yield ceiling of dry beans through the breeding of new varieties were not associated with any significant changes of variance. The implication for breeders is that the selection of desirable traits for crossing can continue without concern for the yield stability.

Another variable of interest was varietal type (seeded). Seeded table grape varieties of the ARC's TGCD Programme returned 2.13 t/ha lower yields, on average, compared to seedless varieties ($P < 0.1$) (Table 1, Just-Pope Yield), *ceteris paribus*. Normally, there are inherent differences across different species (Dlamini et al. 2017). For example, seedless varieties may generally give higher yields when compared with seeded table grapes. The opposite case may also hold. The coefficient for the seeded variable is interesting because it is a measure of the average difference in per-hectare yields between a seedless variety and a seeded variety of the same release year. This means that, if seedless and seeded varieties released in the same year are taken together, the seeded variety yields, on average, 2.13 t/ha lower per hectare than the seedless variety. This supports the fact that there are inherent differences in the types of table grapes.

The above reasoning and inclusion of this dummy variable are based on the fact that the multiple regression implies a control of other factors, such as release year, such that the 2.13 yield differential cannot be explained by different release years. Nhemachena, Kirsten, and Liebenberg (2019) also found different wheat (winter and summer) varieties to be associated with different genetical improvements of 0.84 and 0.5, respectively. This distinction is important as it has huge implications for estimation and helps to avoid the downward biasedness of the estimates that could result if the varietal type dummy variable was excluded. So, in the context of the present study, the existential differences in the genetical gains for the two species imply that there are more opportunities for table grape breeders to push the yield ceiling for seeded varieties than there are for seedless varieties. Moreover, the type of variety had no influence on yield variance ($P > 0.1$), holding other factors constant (Table 1). This means that the TGCD programme has had no effect on the risk related to the two types of varieties. Thus, farmers can continue to adopt any type of the ARC table grape varieties, without worry, because there are no inherent yield risk differences.

BCR and MIRR results

The BCR and MIRR were estimated for the period 2008–2017. The estimated BCR and MIRR efficiency values were limited to seven popular (widely differing) varieties of the ARC, for which consistent producer yield data was available for the period under consideration and did not end up at experimental level. This is because the ARC's TGCD programme experiences high competition from international breeding organizations, such as the Agriculture Research Service of the United States Department of Agriculture (USDA). The USDA released the Crimson seedless table grape variety that is currently a leading variety in South Africa in terms of production and exports. Expert opinion provided by SATI helped in the selection of these varieties, which was also based on the availability of the data.

The estimation yielded a BCR of 4.85, suggesting that every South African rand of public funds invested in the ARC's TGCD programme is associated with a R4.58 return in benefits. In addition, the MIRR was calculated to gauge the research efficiency and was found to be 18%. The BCR and MIRR estimates are to be interpreted with caution, since they are derived from the seven popular ARC varieties. Nevertheless, the results compare well with other studies that have estimated rates of return to breeding research, both in South Africa and elsewhere in the world. Hence, the BCR estimate is comparable with the results of Nalley, Barkley, and Featherstone (2010) and Dlamini et al. (2017) for the breeding of wheat and dry beans, respectively. Nevertheless, the above BCRs, including that of this study, are in contrast with the findings of Nhundu et al. (2019), who found that breeding for quality in wheat is associated with a BCR of 0.62 in South Africa.

Conclusion and recommendations

This study aimed to determine the impact of the ARC's TGCD programme on the South African table grape industry. According to the study results, the ARC's TGCD programme has had significant and positive economic impacts on the yields of table grapes. Moreover, the contribution towards yield is not at the expense of stability. The programme benefits are greater than the programme costs. The results of this paper contribute to the growing body of knowledge that breeding programmes continue to boost yields.

Several implications for policymakers and other relevant stakeholders, such as breeders and farmers, arise from this study. High RORs suggest that there is room for increasing investments in TGCD programme by policymakers. Table grape producers could derive greater benefits by growing more varieties of seedless table grapes, since they are not only favourable to consumers, but also give higher yields per hectare than seeded varieties do, despite pruning and all other necessary yield-reducing activities. Table grape breeders should look for more ways to breed quality seeded table grapes, as there are still huge yield gaps between the two types of varieties. Moreover, the breeding of seedless varieties should continue as they present greater economic benefits for producers. The TGCD should be restructured and include beneficiaries of policy reform programmes so that smallholder table grape farmers can also benefit from the programme. This could increase the adoption rates of the ARC table grape varieties, as well as expand the programme to other regions of South Africa where table grapes have not been previously grown.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Note

1. Culdevco is a joint venture initiative, formed by ARC and South African Deciduous Fruit Industry in 2006, for the commercialization of all ARC-bred varieties.

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Appendices

Table A1: Regression results of unadjusted yields from the ordinary least squares (OLS) and Just-Pope production functions.

Variable	OLS yield	Just-Pope yield	Just-Pope variance	Mean yield (t/ha)
Intercept	1.98 (1.93)	3.006 (2.12)	−45.94 (44.77)	23.50
RLYR	0.01 (0.0009)***	0.01 (0.001)***	0.02 (0.22)	
Seeded	0.004 (0.025)	0.02 (0.025)	−0.09 (0.59)	
Adjusted R^2	0.29	0.83	0.008	

Notes: Significance levels are as follows $*P < 0.1$; $**P < 0.05$; $***P < 0.01$. RLYR, release year

Source: Stata output

Table A2: ARC varieties in their ascending order of release with their assigned numbers and adjusted unadjusted yields.

Cultivars	Cultivar numbers according to their release years	Unadjusted average yield	Adjusted average yield
Muska	1	23,2	2,144,817
Pirobella	2	23,25	2,154,072
Jakaranda	3	23,225	2,205,721
Golden City	4	23,365	2,232,393
Erlihane	5	23,305	2,683,639
Bien Donné	6	23,325	2,845,333
Ronelle	7	23,375	4,057,713
Rosete	8	23,386	2,838,067
Bellevue	9	23,394	2,870,998
Dauphine	10	23,305	2,273,987
Belair	11	23,375	2,331,797
Pêrel	12	23,405	2,337,787
Rubistar	13	23,415	2,339,785
Sonita	14	23,415	2,198,069
Bonheur	15	23,425	2,199,947
Bonita	16	23,505	2,214,999
Muscat Seedless	17	23,505	2,214,999
La Rochelle	18	23,505	2,214,999
Esmeralda	19	23,515	2,641,987
Sunred seedless	20	23,525	2,681,474
Muscat Supreme	21	23,605	2,429,727
Eclipse seedless	22	23,615	2,564,408
Majestic	23	23,625	2,566,581
Muscat Supreme	24	23,605	2,429,727
Rodette	25	23,615	2,584,078
Lady Ann	26	23,625	2,606,583
White gem	27	23,625	2,606,583
Sundance Seedless	28	23,625	2,606,583
Regal Seedless	29	23,625	2,606,583
Muscat delight	30	23,635	23,635
Ebony star	31	23,645	2,306,802
Autumn Queen	32	23,655	3,294,083
Scarlet Dew	33	23,655	3,294,083
Black Velvet	34	23,665	3,360,345
Desert Dawn	35	23,665	3,341,692
Rosidawn	36	23,665	3,341,692
Joybells	37	23,675	4,046,866