Diversification of investment amounts in a currency portfolio through GRG and Evolutionary Algorithms

Diversificación de montos de inversión en un portafolio de divisas por medio de GRG y Algoritmos Evolutivos

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KEYWORDS:

Genetic Algorithm, Currency Portfolio, Differential Evolution.

ABSTRACT

Investment portfolios are collections of exchange instruments that aim to generate a maximum gain with a minimal risk, their design, usually done through a series of equations formulated by Harry Markowitz, which have as purpose to build an optimal portfolio from diversification, in other words, to assign to the assets different investment amounts. According to the specialized literature, these are usually calculated by means of a nonlinear programming method called Generalized Reduced Gradient (GRG), and also by evolutionary algorithms such as the Differential Evolution algorithm and the Genetic Algorithm in binary codings or Gray. This proposal presents the construction of an alternative investment portfolio called a currencies portfolio composed of six currencies yields regarding the Mexican peso. The amounts to be invested in each currency are formulated according to different scenarios, solved by the GRG and compared with solutions obtained by a Differential Evolution algorithm and a Genetic Algorithm, the latter demonstrated it is the best calculation option, it should be noted that the heuristic methods were coded with real numbers.

PALABRAS CLAVE:

Algoritmo genético, Portafolio de divisas, Evolución Diferencial.

RESUMEN

Los portafolios de inversión son colecciones de instrumentos bursatiles que tienen como objetivo generar una ganancia máxima con un riesgo mínimo, su diseño, generalmente es realizado por una serie de ecuaciones formuladas por Harry Markowitz, que tienen como propósito construir un portafolio óptimo a partir de la diversificación, es decir, asignar a los activos diferentes montos de inversión. De acuerdo a la literatura especializada, estos se calculan generalmente por medio de un método de programación no lineal llamado Gradiente Reducido Generalizado (GRG) y también por algoritmos evolutivos como el Algoritmo de Evolución Diferencial y el Algoritmo Genético el cual puede ser codificado en un sistema de numeración Gray o por medio del código binario. Esta propuesta presenta la construcción de un portafolio alternativo de inversión llamado portafolio de divisas, compuesto por seis ganancias de divisas con respecto al peso mexicano. Los montos a invertir en cada divisa se formulan de acuerdo a diferentes escenarios, resueltos por el GRG y comparados con las soluciones obtenidas por un algoritmo de Evolución Diferencial y un Algoritmo Genético, este último demostró que es la mejor opción de cálculo, cabe señalar que los métodos heurísticos fueron codificados con números reales.

Recibido: 2 de noviembre 2020 • **Aceptado:** 11 de febrero de 2021 • **Publicado en línea:** 4 de junio de 2021

1 Introduction

An investment portfolio is defined as a set of various investments such as stock of companies, bonds, foreign currency, options, metals, promissory notes, investment projects or in general terms, any instrument that generates financial profits. The objectives for building an investment portfolio are as follows [1]:

1. Prevent financial resources from being placed in a single investment instrument
2. Diversify the probability of loss (risk)
3. Ensure a minimal performance
4. Manage risks from diversifying the investment amounts

Generally speaking, an investment portfolio can be valued in terms of its performance and risk. The first is defined as the percentage of profit or loss generated by the combinations of the amounts to be invested in the assets that make up the portfolio. Moreover, risk is defined as the probability of loss of capital assigned to the portfolio, it depends on the speed and magnitude of change in stock prices [2].

The risk presented in investment portfolios can be reduced through diversification which is a strategy that consists of incorporating several assets in a portfolio, the amounts to be invested are determined by various theoretical positions, the best known is the Harry Markowitz's theory of the optimal portfolio [3]

The Mean-Variance model is a theoretical approach where the owner or holder of a portfolio wants to minimize the risk subject to a minimum expected return level or maximize profitability subject to a desired maximum risk. It was developed by the American economist Harry M Markowitz in 1952 and published in the article "Portfolio Selection" on the Journal of Finance magazine [4][5] The Markowitz model may consider the following aspects:

- The performance of any portfolio is considered a random variable, for which the investor estimates a probability distribution for the study period. The expected value of the random variable is used to quantify the return on investment.
- Variance or standard deviation are used to measure dispersion, as a measure of asset risk; this measurement should be carried out individually, to each asset and to the entire portfolio.
- The rational behavior of the investor leads him to prefer the composition of a portfolio that represents the highest profitability, for a certain level of risk.

Markowitz's theory can be expressed by mathematical expressions such as the one shown in equation 1 [6]

$$\overline{r_p} = \overline{r_1} * w_1 + \overline{r_2} * w_2 + \overline{r_3} * w_3 \ldots \overline{r_n} * w_n \qquad 1$$

Which can be written in terms of summations as shown in equation 2 and represents the performance of the portfolio[6]

$$\overline{r_p} = \sum_{n=1}^{N} \overline{r_n} * w_n \qquad 2$$

Where

$\overline{r_p}$ portfolio average return or profit
$\overline{r_n}$ return on asset
w_n weight or amount to invest in the *n th* asset
N total number of assets

The risk of the portfolio can be modeled by means of equation 3 [6]

$$\sigma_p^2 = \sum_{n}^{N} \sum_{m}^{N} w_n * w_m * \sigma_{nm} \qquad 3$$

where

σ_p^2 is the estimated risk of the portfolio
σ_{nm} is the covariance of returns

On the other hand, the restriction of the problem can be defined by means of equation 4

$$\sum_{n=1}^{N} w_n = 1 \qquad 4$$

The problem expressed by Markowitz's theory is about obtaining the weights to be invested to ensure the highest yield $\overline{r_p}$ with the minimum value σ_p^2.. Therefore, this is an optimization problem.

Currently, investment portfolios theories acquire a relevant importance in a volatile economic environment for domestic economic policy issues in countries such as Mexico (cancellation of infrastructure contracts and uncertainty about economic activation, to mention a few). These conditions make the holders of investment portfolios to have an aversion to public or private debt instruments and choose to invest in currency portfolios, a class of investment portfolio that is composed of foreign currencies susceptible to be built through the Markowitz's optimal portfolio theory.

This work proposes the formulation of an optimal currency portfolio, for this, a nonlinear programming method called generalized reduced gradient and two evolutionary methods were tested: The Canonical Genetic algorithm and the Differential Evolution algorithm

1 Optimization of an investment portfolio

One of the areas of engineering is optimization, which is defined as a set of techniques that find the best solution to problems of daily life in areas such as engineering, transport and economics, as long as they are susceptible to being mathematically modelable with a function scheme $f(x_1, x_2, \dots x_n)$ minimizeable or maximizable by means of a solution vector of the form $\vec{x} = \{x_1, x_2, \dots x_n\}$ under the presence or absence of certain conditions called constraints.

Mathematically, a P optimization problem without restrictions can be formulated as terna $P = (f, SS, F)$, defined as shown in equation 5 [7].

$$P = \begin{cases} opt:\ f(x), \\ s.a, \\ x \in F \ \subset SS \end{cases} \quad 5$$

Where *f* is the function to optimize (you want to find its maximum or minimum), F the set of feasible solutions and SS the solution space.

On the other hand, a problem P with restrictions can be modeled as in equation 6 [8]

$$P = \begin{cases} opt: min\ f(x), \\ s.a, \\ x = F \begin{cases} x|\ g_i(x) \leq 0, \\ i = 1, 2, 3, .., m, \} \end{cases} \end{cases} \quad 6$$

Where f is the function to optimize (it is wanted to find the minimum or maximum value of this variable), F the set of feasible solutions where x complies the constraints given by $g_i(x) \leq 0$ y $i = 1, 2\ 3, .., m$.

It should be mentioned that for the P optimization problem to be solved, the format of the solution vector is $x = (x_1, x_2, .., \ x_j)$ which complies the set of constraints given and where the objective functions are optimized. The solution space is built from all possible combinations in the range of variables, from this, a second vector space is generated called objective space and denoted by $f_m(x) = z = (z_1, z_2, .., z_m)$ [9]

In the context of optimization problems, the amounts diversification in a investment portfolio is often treated as a mono-objective problem, with restrictions, since one of the main ways to solve it is through the Generalized Reduced Gradient (GRG) method, which considers three possible scenarios

1. Maximize yields, represented by equation 2
2. Minimize risk, represented by equation 3
3. Maximize the relationship of equations 2 and 3

1.1 Generalized Reduced Gradient

One way to solve investment portfolios, is the Generalized Reduced Gradient method to solve an investment portfolio consisting of Real Estate Investment Trust REITs assets in various countries. In [10] the GRG is used to obtain an optimal portfolio in different risk scenarios from 30 assets separated in groups of 10 corresponding to the Amman financial market in the period 2009-2013 with monthly observations. On the other hand, [11] shows the use of GRG in the construction of an investment portfolio consisting of 10 assets, where the amounts to be invested in them are calculated from a moderate risk profile. These works documented in specialized literature have in common the use of Microsoft Excel and the Solver add-in to implement the GRG.

The Generalized Reduced Gradient model is a method used when an optimization problem has constraints (in the case of the portfolio this is expressed in equation 4) extending the linear method of Reduced Gradient.

At the starting point of the GRG search it must comply with the conditions of the optimization problem to be solved (equation 2 or 3, it depends on the portfolio profile). If this happens, the algorithm modifies the solution in a descent direction complying the constraints, repeating this operation iteratively to a point where the algorithm cannot find a modification direction of the individual where the objective function could be reduced.

1.2 Evolutionary Algorithms

An alternative solution to the problem of optimizing an investment portfolio are evolutionary algorithms, which are a set of computational methods that are theoretically supported on the Theory of Species Evolution formulated by Charles Darwin and the laws of inheritance discovered by Gregory Mendel.

EAs operate from a collection of potential individuals that can be represented by the vector $P(t) = \{x_1^t, x_2^t, \dots, x_n^t\}$ called population, each element *P(t)* represents a possible feasible solution to a numerical or combinatorial optimization problem. This population undergoes recombination and transformation operations, subsequently to a selection process which is performed iteratively [12], after a certain number of iterations the best individual (the one who generates the highest value of the aptitude function) is expected to converge to a certain point that will be considered the solution to an optimization problem [13]

EAs are characterized by start from a set of initial solutions that are transformed by the action of a set of operators, which are responsible for "refining" the solutions until they converge to a certain point called solution. The structure of an evolutionary algorithm is shown in Fig 1, which allows to observe the iterative nature of this type of computational algorithm [14]

It is important to note that there are as many evolutionary algorithms as there are biological principles, since, in general terms there is no universal algorithm for solving optimization problems. That is, a technique that was successful in an environment will not necessarily work in the same way in another situation [7]. This is theoretically developed by David Wolpert and William Macready in the No Free Lunch theorem [15]

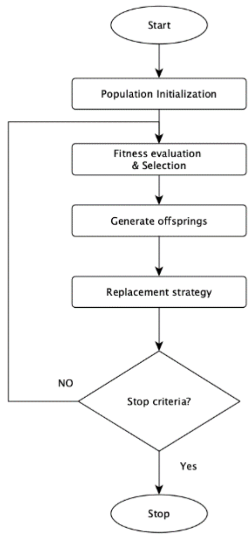

Fig. 1. Flow diagram of an evolutionary algorithm

1.2.1 Genetic Algorithm

John Holland from the University of Michigan developed the Genetic Algorithm in the 1960s [16], it is a useful technique of solving optimization problems since it is not necessary to have a deep knowledge of the problems that are proposed to solve, only random changes are made to the possible solutions, evaluating with the objective function to verify if they reach an improvement.

Some limitations and disadvantages of genetic algorithms with respect to other evolutionary techniques are [17], [18] and [19]

• An incorrect selection of the objective function impacts the algorithm's ability to find the correct solution to the problem.

• The size of the population, the rhythm of the mutation and crossover should be delimited because, if the population is small the algorithm may not explore the entire solution space.

• That the algorithm can converge prematurely, if the optimal solution appears too soon, diminishing solutions and reaching a local optimal rather than exploring the entire space and reaching the global optimal.

Fig.2 shows the flowchart of a simple or Canonical Genetic Algorithm, for solving a mono-objective optimization problem:

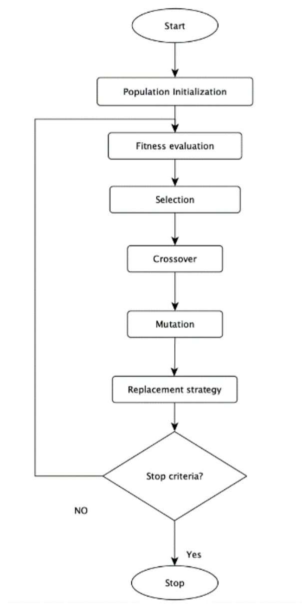

Fig. 2. Flow diagram of a genetic algorithm

One of the most widely used crossover operators is the Blend Crossover (BLX- α), implemented in this proposal, from two parent chromosome $C^{H1}\ y\ C^{H2}$, randomly generates a descendant, starting from the expression 6 [18]

$$C^H = rand[(h_{min} - I * \alpha), (h_{max} + I * \alpha)] \quad 6$$

Where C^H is the descendant chromosome$h_{min} = min(C_i^1, C_i^2)$, $h_{max} = max(C_i^1, C_i^2)$, $I = h_{max} - h_{min}$, $\alpha = rand[0,1]$ with uniform distribution. It should be noted that descendants can be produced as needed.

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For the mutation, the use of gaussian mutation is proposed, an operator responsible for modifying a specific C chromosome randomly chosen by means of a gaussian probability distribution of mean 0 and variance defined as shown in the expression 7 for each g gene g [14]

$$\sigma_k = \frac{T-t}{T}\frac{\left(g_k^{max} - g_k^{min}\right)}{3} \quad 7$$

Where t is the current generation, T is the maximum number of generations contemplated in the algorithm in such a way that the mutated chromosome can be defined as shown in 8

$$C' = C + N(0, \sigma_k) \quad 8$$

1.2.2 Differential Evolution Algorithm

The Differential Evolution algorithm is a heuristic technique that emerged as a numerical optimization technique, developed in 1994 by Kenneth Price and Rainer Storn, professors from Berkeley California. The DE uses a simple mutation operator that is based on the difference of solution pairs (called vectors), this allows to determine a search direction based on the set of vectors that is called population [19]

Recombination and mutation are the variation operators used to generate new solutions, and a replacement mechanism provides the capacity to maintain a size in the population. The replacement strategy is based on the competition between the descendant vectors of the recombination process (children) with those of the original population, which is generated by a normal probability distribution. The mutation aims to generate variations that move the solution vectors in the correct direction and magnitude and is represented in its simplest form in the equation (9) [20]

$$\vec{v}_G = \vec{x}_{r3,G} + F\left(\vec{x}_{r1,G} - \vec{x}_{r2,G}\right) \quad 9$$

where
$F\epsilon$ [0,1] is a scale factor that controls the vector difference described in $\vec{x}_{r1,G} - \vec{x}_{r2,G}$
G current generation
$r1 \neq r2 \neq r3$ represent the indices of the vectors used in the mutation operator

On the other hand, recombination allows the exchange of information between the parent vector and the mutant vector generating a descendant $\vec{u}$, where each of the elements of the child can be taken from the parent vector or mutation vector with a probability determined by the *CR* parameter which is within the interval [0,1], this operator is described in equation 10

$$\vec{u}_{i,G} = \begin{cases} \vec{u}_{i,G}\ \forall\, rand\ [0,1] < CR \\ \vec{x}_{i,G} \quad for\ another\ case \end{cases} \quad 10$$

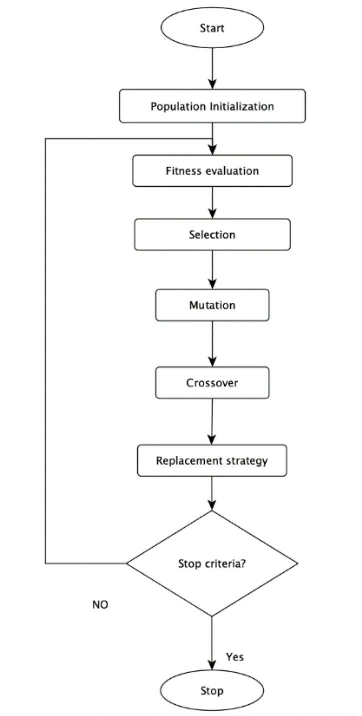


Fig. 3. Flow diagram of a Differential Evolution algorithm

2 Methodology

For the amounts diversification by genetic and differential evolution algorithms the following objective function is proposed, built from equations 2 and 3, obtaining [11]

$$f_{obj} = max \frac{\sum_{n=1}^{N} \overline{r_n} * w_n}{\sum_{n}^{N} \sum_{m}^{N} w_n * w_m * \sigma_{nm}} \qquad 1\ 1$$

The proposed coins' yields for the portfolio development can be obtained by means of the expression 12, which is applied daily for 3 months

$$r_n = ln \frac{p_c}{p_p} \qquad 1\ 2$$

where

r_n is the yield of the *nth* currency

p_c current currency price

p_p previous price of the nth currency

The methodological scheme proposed for this investigative process is shown in figure 4, which shows the application of the proposed algorithms, in order to obtain an optimal currency portfolio.

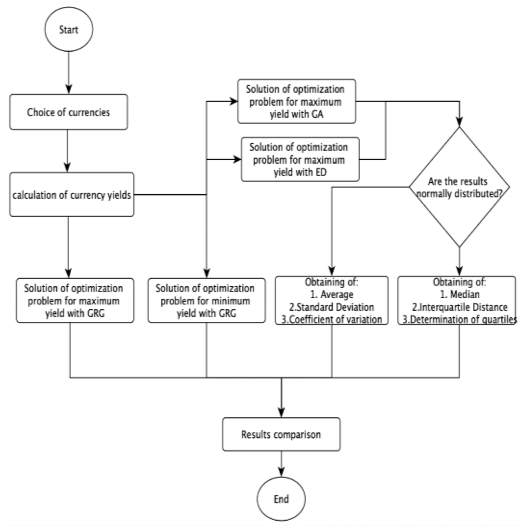


Fig. 4. Proposed methodological scheme.

The conditions for evolutionary algorithms experimentation are shown in table 1

Table 1. Experiments for evolutionary algorithms

Test	Technique	Percentage of crossver	Percentage of mutation	Elements of the initial population
1	GA	80%	1%	60
2	ED	random	random	100

For the statistical study it is necessary first, to carry out a study on the normality or absence of it in the results obtained from the function shown in equation 6, for which the Lilliefors test is used, a variant of the Kolmogorov-Smirnov test, which assumes that the mean and standard deviation of the data obtained is not known.

The comparison of results, in the first stage, will consist of an analysis of the statistical differences between experiments 1 and 2 from the Anova test, to be compared later with the values obtained in scenarios 1, 2 and 3 described in the introduction section.

3 Results

The currencies to be used for this proposal with their corresponding average returns in a three-month time window is shown in Table 2

Table 2. Average returns on currencies

Divisa	Mean
Real	-0.01952%
Dollar.C	0.11973%
Eur	0.19384%
DolaA	0.12662%
Libra	0.12143%
yen	0.16994%

When applying the Lilliefors test to the results of the objective function, described in equation 6, obtained with the algorithm corresponding to test 1, results in a significance value p= 0.297, a value greater than the significance of 0.05, so it can be assumed that the results of the optimized portfolio have a normal distribution, therefore, it is possible to obtain the statistics shown in Table 3

Table 3. Statistics for the experiment corresponding to GA

Measure of central tendency	Value
Average	9.04849
Standard Deviation	0.01884077
Coefficient of variation	0.20822%

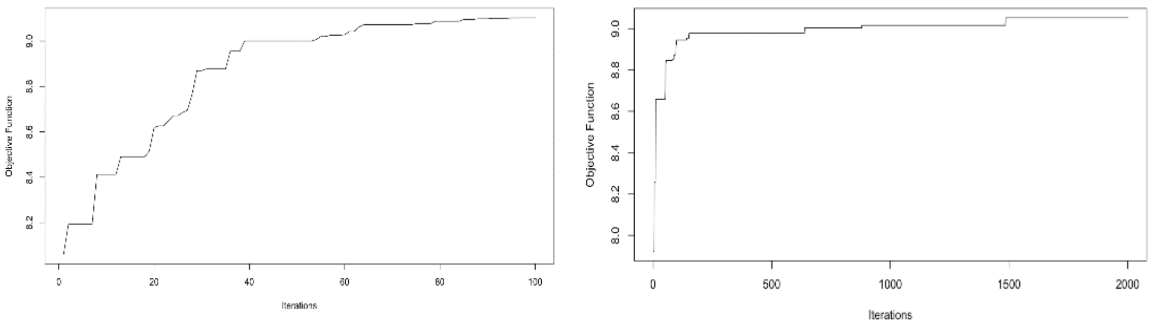
When applying the Lilliefors test to the results of the objective function, described in equation 6, obtained with the algorithm corresponding to test 2, results in a significance value p= 3.269e-14, a value less than the significance of 0.05, so it can be assumed that the results of the optimized portfolio do not have a normal distribution, therefore it is possible to obtain the statistics shown in Table 4

Table 4. Statistics for the experiment corresponding to the ED

Measure of central tendency	Value
Median	9.114084
Interquartile Distance	0.11973%
Quantile 0%	9.079851
Quantile 25%	9.112919
Quantile 50%	9.114084
Quantile 75%	9.114133
Quantile 100%	9.114137

The Figure 5 shows the convergence of both algorithms, where it is observed that the fastest convergence corresponds to test 2.

The Figure 6 shows the results of the obtained optimizations, showing the percentages of gain and risk for each of the proposed scenarios and experiments. Besides, Figure 7 shows the weights to be invested for each of the proposed scenarios and experiments, which meet the condition of sum=1



(a) (b)

Fig. 5 Convergence of the proposed algorithms, for Differential Evolution (a) and for the Genetic Algorithm (b)

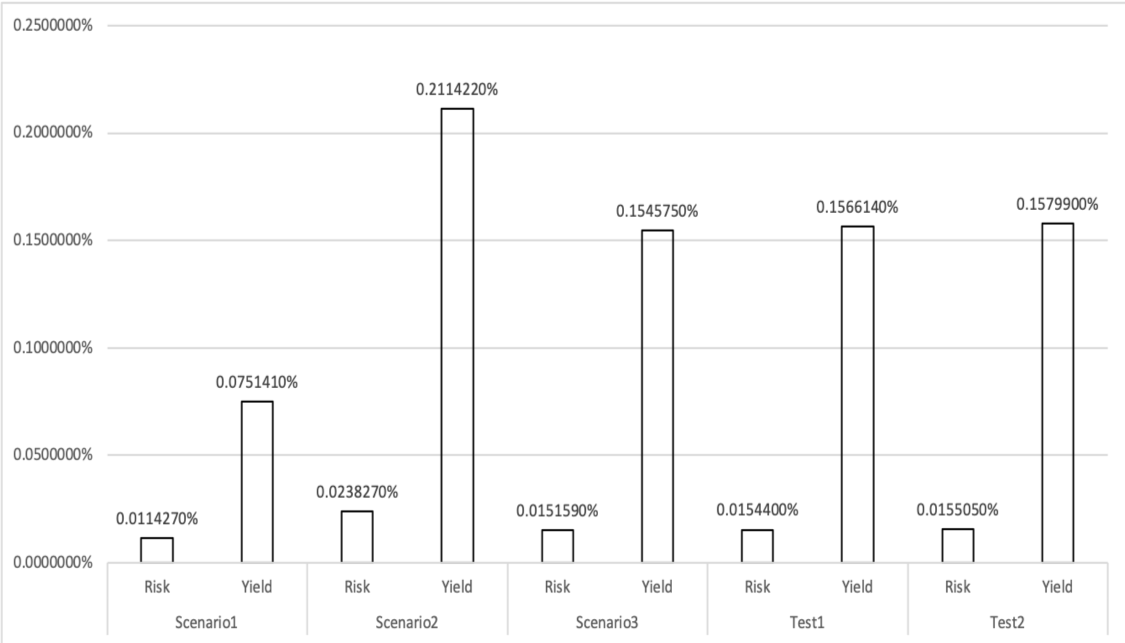


Fig. 6. Risk and profit results for each of the proposed scenarios and experiment

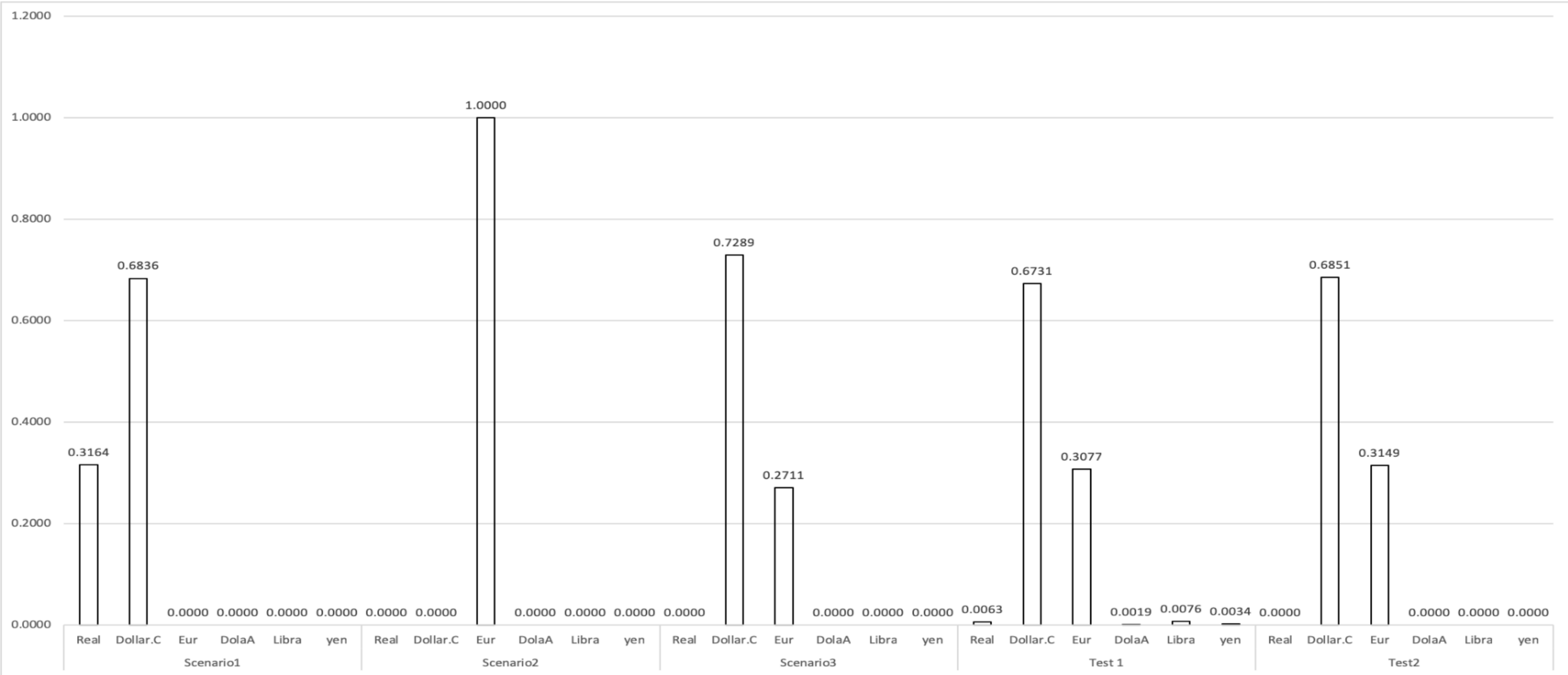


Fig. 7 Weights to invest in currencie

4 Conclusions

As shown in Figure 6 the GRG method in the proposed scenarios fulfills its purpose of risk reduction, gain maximization and maximization of gain/risk ratio, this is coupled to the following profiles

- High aversion to risk, that is to say, the lowest possible value for equation 3
- Low aversion to risk, that is the maximum value for equation 2 is privileged
- The maximum relationship between equation 2 and 3

Scenario 2, according to Figure 6, has the best gain outlook, but in turn the highest risk, on the other hand, scenario 3 shows a balanced profile between the minimum risk and the maximum gain. The evolutionary algorithms discussed in this proposal improve the gain/risk relationship with respect to the GRG, although an apparently small difference is reported this has a significant impact when the portfolio has a long-term possession period.

It is relevant to mention that the best algorithm for solving the problem presented would be the Genetic Algorithm, which despite having a lower gain value than the ED also has a lower risk (according to Figure 6) and respects the principle formulated by the diversification of Markowitz, that is, the distribution of the weights to invest in several assets, since the other techniques discussed in this proposal concentrate the weights on one or two assets, while the GA allocates amounts to invest for the entire portfolio, this is demonstrated in Figure 7.

It is important to note that the proposed Anova test was not carried out since the probability distributions for GA and ED are different, therefore it is assumed that they are different algorithms.

As an area of opportunity is appropriate to implemement a micro genetic algorithm, this in order to improve the convergence found for this proposal in 2000 iterations according to Figure 5b, this is slower than that of the ED found in 100 iterations (Figure 5a). It should be noted that the performance of this hypothetic new experiment would be subject to similar steps described in the investigative process in figure 4

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