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Comparison of Markowitz and Genetic Algorithm Models for Saudi Arabian Stocks

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Abstract: This study aims to compare the Markowitz method and the Genetic Algorithm in forming an optimal portfolio in the Saudi Arabian stock market, which is known to have dynamic characteristics and high levels of volatility due to the influence of economic reforms, oil price fluctuations, and integration with global markets. The study uses daily closing price data for companies indexed in the Tadawul All Share Index for the period January 2, 2022, to October 30, 2025, obtained through Yahoo Finance. Sample selection uses a purposive sampling method based on data completeness and Coefficient of Variation selection. The optimization process is carried out using the Python programming language through the Efficient Frontier Markowitz approach and the Genetic Algorithm. While portfolio performance evaluation is carried out using the Sharpe Ratio, Sortino Ratio, and Omega Ratio to obtain a more comprehensive assessment of risk and return efficiency. The results show that the Markowitz method tends to produce higher expected returns, but with a greater level of risk, while the Genetic Algorithm produces a portfolio with a relatively lower level of risk and more stability. Furthermore, conventional stock portfolios performed better than Islamic stock portfolios based on the performance ratio evalu-ation used. This finding suggests that portfolio optimization methods should be tailored to investor risk preferences and the characteristics of the investment market.

Keywords: Optimal Portfolio; Markowitz; Genetic Algorithm; Efficient Frontier; Saudi Arabian Stocks

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1. Introduction

Stock investment is a highly sought-after investment instrument due to its ability to generate relatively high returns compared to other financial instruments. In practice, investors do not focus solely on maximizing returns but also consider the level of risk involved. Consequently, constructing an optimal portfolio is a crucial aspect of investment decision-making, as the goal is to create an asset combination that yields the maximum return for a given level of risk. A diversification strategy involving portfolio construction is essential to minimize investment risk without compromising the potential returns available to the investor [5].

In modern portfolio theory, the concept of the efficient frontier developed by [14] serves as the fundamental basis for constructing an optimal portfolio. The Markowitz model explains that investors can achieve the best portfolio combination by optimizing the relationship between expected return and portfolio risk. This approach utilizes variance and covariance among assets to determine an efficient investment composition. The efficient frontier concept illustrates a set of optimal portfolios that offer the highest return for a given level of risk or the lowest risk for a given level of return. Due to its ability to systematically explain the relationship between risk and return, the Markowitz model remains one of the most widely used methods in investment management [19].

Nevertheless, the Markowitz model has certain limitations regarding its application in modern stock markets. It is built on the assumptions that stock returns are normally distributed, relationships between assets are linear, and market conditions are stable. In reality, stock markets often exhibit dynamic, volatile, and non-linear movements, making it difficult to fully satisfy these assumptions. Furthermore, the Markowitz approach is sensitive to changes in input data such as expected returns and the covariance matrix meaning optimization results can shift significantly during market fluctuations. Consequently, the Markowitz model is considered less flexible in handling the complexities of rapidly evolving markets [17].

These characteristics are evident in the Saudi Arabian stock market, represented by the Tadawul All Share Index. As the largest capital market in the Middle East, the Saudi stock market plays a significant role in the regional economy. Its development has been shaped by the Vision 2030 economic reforms, fluctuations in global oil prices, integration into global markets, and increased foreign investor participation. According to an MSCI report, the market has experienced improved liquidity and accessibility for global investors since its inclusion in the MSCI Emerging Markets Index. However, this rise in trading activity has also been accompanied by high market volatility [3].

In addition to being influenced by external factors, the Saudi stock market exhibits internal characteristics indicating that its level of market efficiency is not yet fully stable. Research [13] has found that the Saudi stock market possesses "long memory" properties signifying long-term dependency and thus does not yet fully satisfy the efficient market hypothesis. The market continues to experience inefficiencies despite undergoing various governance reforms. Furthermore, the dominance of retail investors and high sensitivity to oil prices render the risk-return relationship unstable. These conditions suggest that classical optimization approaches, such as the Markowitz model, may not effectively generate optimal portfolios within the dynamic and non-linear environment of the Saudi stock market [1].

Advancements in computational technology within the financial sector have spurred the emergence of various adaptive alternative optimization methods, one of which is the Genetic Algorithm (GA). The Genetic Algorithm is an evolution-based heuristic method that employs selection, crossover, and mutation processes to identify optimal solutions. This method is considered more flexible than conventional approaches, as it is capable of handling non-linear relationships and complex investment constraints, while also mitigating the risk of becoming trapped in local optima. Studies have demonstrated that the Genetic Algorithm yields more stable portfolio optimization results in highly volatile markets. Research by [12] indicates that the Genetic Algorithm-based heuristic method produces more flexible portfolio optimization solutions compared to conventional approaches when dealing with complex constraints. Furthermore, [27] state that the Genetic Algorithm is effective for portfolio optimization, as it generates solutions approaching the efficient frontier while simultaneously accommodating minimum transaction lot constraints in dynamic market conditions. Recent research on metaheuristic portfolio optimization [6] also highlights the increasing adoption of heuristic approaches and evolutionary algorithms, noting their superior effectiveness in solving the complex, non-linear optimization problems characteristic of modern portfolio management [15].

While extensive research has been conducted on portfolio optimization, studies specifically comparing the performance of the Markowitz Efficient Frontier method and the Genetic Algorithm within the Saudi Arabian stock market remain relatively limited. Most prior research has focused on developed markets or employed only a single optimization method without conducting a direct comparison. Therefore, this study aims to compare the performance of the Markowitz Efficient Frontier and the Genetic Algorithm in constructing optimal portfolios of Saudi Arabian stocks. This research is expected to contribute academically to the development of portfolio optimization methods and serve as a practical reference for investors in determining more effective investment strategies tailored to the characteristics of the Saudi stock market [25].

2. Literature Review

2.1. Modern Portfolio Theory (MPT)

Modern Portfolio Theory (MPT) was introduced by Harry Markowitz as an approach to constructing an optimal portfolio by combining assets to achieve the maximum possible return for a given level of risk. The theory emphasizes that investment decisions should not rely solely on the individual performance of assets but also on the interrelationships between assets within a portfolio, utilizing the concept of diversification. In this model, risk is measured using variance or standard deviation, while asset interrelationships are analyzed through covariance and correlation. Markowitz's approach gave rise to the concept of the "efficient frontier" a set of efficient portfolios that offer the highest return for a specific level of risk. However, the model has limitations; it is built on assumptions of normally distributed returns and linear relationships between assets, meaning its application in dynamic and volatile markets is often suboptimal [14]. Research by [18] explains that portfolio diversification can reduce unsystematic risk by combining assets with varying correlation patterns. Consequently, the construction of an optimal portfolio is a crucial component of modern investment management [20].

Although the Markowitz model remains one of the most influential portfolio optimization approaches, recent studies have highlighted several practical limitations. The model relies heavily on accurate estimates of expected returns and the covariance matrix, making portfolio allocation highly sensitive to estimation errors. Moreover, the assumptions of normally distributed returns and linear asset relationships often fail to reflect actual financial market behavior, particularly during periods of high volatility and market uncertainty. Consequently, optimization results may become unstable when market conditions change rapidly. Recent systematic reviews suggest that these limitations have encouraged researchers to integrate computational intelligence and metaheuristic optimization techniques into modern portfolio management, allowing more flexible portfolio construction while maintaining efficient risk-return characteristics [28].

2.2 Genetic Algorithms in Portfolio Optimization

Among various computational intelligence methods, the Genetic Algorithm (GA) has become one of the most widely used optimization techniques in portfolio management. GA imitates biological evolution through selection, crossover, and mutation processes to search for optimal portfolio allocations. Unlike classical optimization methods, Genetic Algorithm does not require strict mathematical assumptions and is capable of handling nonlinear optimization problems with multiple constraints. Recent studies have confirmed the effectiveness of Genetic Algorithm in portfolio optimization. [10] reported that Genetic Algorithm provides robust solutions under uncertain market conditions and improves portfolio diversification compared with conventional optimization approaches. [11] proposed an evolutionary multi-objective optimization framework that successfully generated portfolios with more balanced risk-return characteristics than traditional mean-variance optimization.

The Genetic Algorithm (GA) is an evolution-based optimization method that adopts natural selection mechanisms specifically selection, crossover, and mutation to derive an optimal solution from a population of candidates. In portfolio optimization, each chromosome represents a combination of asset weights to be optimized based on a specific objective function, such as maximizing returns and minimizing risk. [8] demonstrated that optimization methods can effectively determine portfolio allocations by considering the interactions among financial assets, thereby producing more efficient investment decisions under portfolio constraints.Compared to conventional approaches like the Markowitz model, the Genetic Algorithm is considered more flexible due to its ability to handle non-linear relationships, complex investment constraints, and vast solution spaces. Research by [7] demonstrates the effectiveness of the Genetic Algorithm-based heuristic approach in portfolio optimization subject to various investment constraints, while [9] notes that the method yields portfolio solutions that are more adaptive to dynamic market conditions. Consequently, the Genetic Algorithm is widely employed in modern portfolio optimization, particularly in markets characterized by high volatility and instability. According to [16], the Genetic Algorithm offers superior global search capabilities compared to traditional optimization methods, as it can avoid local optima in complex optimization problems.

Despite its superior flexibility, the Genetic Algorithm is not without limitations. The quality of the optimization results depends greatly on parameter settings such as population size, crossover probability, mutation rate, and stopping criteria. Inappropriate parameter selection may lead to premature convergence or excessive computational time. Nevertheless, compared with classical optimization techniques, Genetic Algorithm provides stronger global search capability and is more suitable for solving portfolio optimization problems involving multiple objectives and nonlinear investment constraints. Recent studies by [10] and [11] demonstrated that evolutionary optimization methods consistently outperform conventional optimization in terms of robustness and diversification under uncertain market conditions.

2.3 The Efficient Frontier and Portfolio Performance Ratio Analysis

The efficient frontier concept is a cornerstone of modern portfolio theory, representing the set of optimal portfolios that yield the highest return for a given level of risk. The efficient frontier curve illustrates the relationship between expected return and portfolio risk measured by standard deviation enabling investors to select investment combinations that align with their individual risk preferences. When evaluating portfolio performance, various ratios are employed to assess the efficiency of optimization outcomes. The Sharpe Ratio, introduced by [22], measures excess return relative to total portfolio risk, whereas the Sortino Ratio focuses on downside risk, making it particularly relevant for high-volatility markets [23] Additionally, the Omega Ratio is used to evaluate the overall distribution of gains and losses, as it considers factors beyond mere average return and variance [21]. Utilizing these three ratios allows for a more comprehensive performance evaluation when comparing the effectiveness of the Markowitz method and the Genetic Algorithm in constructing optimal portfolios. Research by [26] indicates that employing the Sharpe, Sortino, and Omega ratios in tandem provides a more comprehensive performance assessment than relying on a single ratio alone. This approach is considered more effective for measuring risk-return efficiency within volatile and dynamic market conditions [4]. Based on the strengths and limitations of both optimization methods, this study compares the performance of the Markowitz Efficient Frontier and the Genetic Algorithm in constructing optimal portfolios of Saudi Arabian Sharia and conventional stocks. The comparison is expected to provide empirical evidence regarding the effectiveness of both methods under the characteristics of the Saudi capital market while contributing to the development of portfolio optimization research.

3. Research Methods

This study employs a quantitative approach with a comparative method to compare the performance of Markowitz's Efficient Frontier and the Genetic Algorithm in constructing an optimal portfolio within the Saudi Arabian stock market. A quantitative approach is utilized because the study focuses on processing numerical data specifically stock returns, risk levels, and portfolio performance metrics. Meanwhile, the comparative method is used to analyze differences in the optimization results yielded by the two methods in forming an optimal portfolio.

The study utilizes secondary data consisting of daily closing prices for companies listed on the Tadawul All-Share Index over the period from January 2, 2022, to October 30, 2025. Data were obtained via Yahoo Finance and processed using the Python programming language. The selected study period aims to capture a picture of the dynamic conditions of the Saudi Arabian stock market, including the impact of market volatility, fluctuations in oil prices, and global investor activity influencing stock movements. Companies with incomplete daily closing price data for the specified period were excluded to ensure the study's accuracy based on stock price performance data.

The population for this study consists of all companies listed on the Tadawul All Share Index during the observation period. A purposive sampling method was employed, selecting companies that possessed complete daily closing price data throughout the study period. Following the screening process, the qualifying stocks were evaluated using the Coefficient of Variation (CV) to identify those demonstrating superior risk-return efficiency; stocks with lower CV values were selected as the study sample. Subsequently, the selected stocks were categorized into three portfolio groups: Sharia stocks, conventional stocks, and a combined group of Sharia and conventional stocks.

Optimal portfolio construction in this study was achieved using the Markowitz Efficient Frontier method and the Genetic Algorithm. The Markowitz method was utilized to generate efficient portfolio combinations based on the risk-return relationship, while the Genetic Algorithm served as an alternative optimization method, offering greater flexibility in exploring asset weight combinations under complex market conditions. Mathematically, the construction of the optimal portfolio was based on the portfolio's expected return. Portfolio performance was evaluated using the Sharpe Ratio, Sortino Ratio, and Omega Ratio to compare the risk-return efficiency of each method. The entire process spanning data acquisition, data processing, and portfolio optimization through to result visualization was conducted using Python, supported by libraries such as yfinance, pandas, NumPy, SciPy, and Matplotlib, ensuring a systematic and efficient analysis.

The sample selection process was conducted systematically to ensure that the selected stocks represented the characteristics of both Sharia-compliant and conventional stocks listed on the Tadawul All Share Index (TASI). Initially, all eligible stocks were identified and classified into their respective categories. Stocks with incomplete daily closing price data during the observation period were excluded to ensure consistency in the calculation of returns and risk.

Subsequently, the Coefficient of Variation (CV) was used as the primary screening criterion. The CV measures the ratio of the standard deviation to the expected return, indicating the level of risk associated with each unit of expected return. Stocks with lower CV values were considered more efficient because they provided lower risk relative to their expected returns. Therefore, the CV was employed to identify stocks with favorable risk-return characteristics before portfolio optimization. Based on the CV ranking, six Sharia-compliant stocks and six conventional stocks with the lowest CV values were selected as the final sample. An equal number of stocks from each category was chosen to ensure a balanced comparison between Sharia and conventional portfolios while maintaining computational efficiency during the optimization process.

The Coefficient of Variation (CV) was selected because it standardizes portfolio risk relative to expected return, enabling objective comparison among stocks with different return characteristics. Stocks with lower CV values provide lower risk per unit of expected return and are therefore considered more efficient investment candidates. This criterion has been widely adopted in portfolio screening to improve the quality of asset selection before optimization.

Table 1. Sample and Population

CRITERIA	AMOUNT
Stocks included in the Tadawul All-Share Index	50
Total Population	50
Stocks with incomplete closing price data	38
Total	12
Stocks listed only on conventional indices	6
Stocks listed exclusively on Sharia indices.	6
Total samples	12
Total data (12 stock x 955 days)	11.460

As presented in Table 1, the final sample consisted of six Sharia-compliant stocks and six conventional stocks selected based on the lowest Coefficient of Variation (CV) values. This selection ensured that the portfolio optimization was performed using stocks with relatively efficient risk-return characteristics while maintaining a balanced comparison between both portfolio groups. Six stocks were selected for each portfolio category to ensure balanced comparison between Sharia-compliant and conventional portfolios. Since only six conventional-only stocks satisfied all screening criteria, the same number was adopted for the Sharia portfolio to eliminate sampling bias and maintain comparable optimization conditions across portfolio groups.

The Coefficient of Variation (CV) was calculated for the obtained sample, and the resulting CV values served as the basis for stock selection; stocks with low CVs were chosen. Subsequently, the number of stocks in each portfolio group was determined based on the smallest group size specifically the group listed only on the conventional index, comprising six stocks to ensure fairness and avoid bias. Finally, a combined group was added, consisting of stocks from all three aforementioned groups, totaling 12 stocks.
The stocks for each portfolio group are as follows:

Table 2. Selected stocks and their portfolio groups

CONVENTIONAL ONLY	SHARIA ONLY	COMBINATION
Arabian United Float Glass	Bank Aljazira	Arabian United Float Glass
Saudi British Bank (SABB)	Almarai	Saudi British Bank (SABB)
Riyad Bank	Yamama Cement	Riyad Bank
Al Baha Investment	Saudi Investment Bank	Al Baha Investment
SADAFCO	Al Rajhi Bank	SADAFCO
Seera Group	Bank Albilad	Seera Group
		Bank Aljazira
		Almarai
		Yamama Cement
		Saudi Investment Bank
		Al Rajhi Bank
		Bank Albilad

3.1. Research Flowchart

This flowchart illustrates the systematic stages of the research, ranging from problem identification to the drawing of conclusions. The research process focuses on comparing the Markowitz method and the Genetic Algorithm in constructing an optimal portfolio of Saudi Arabian stocks.

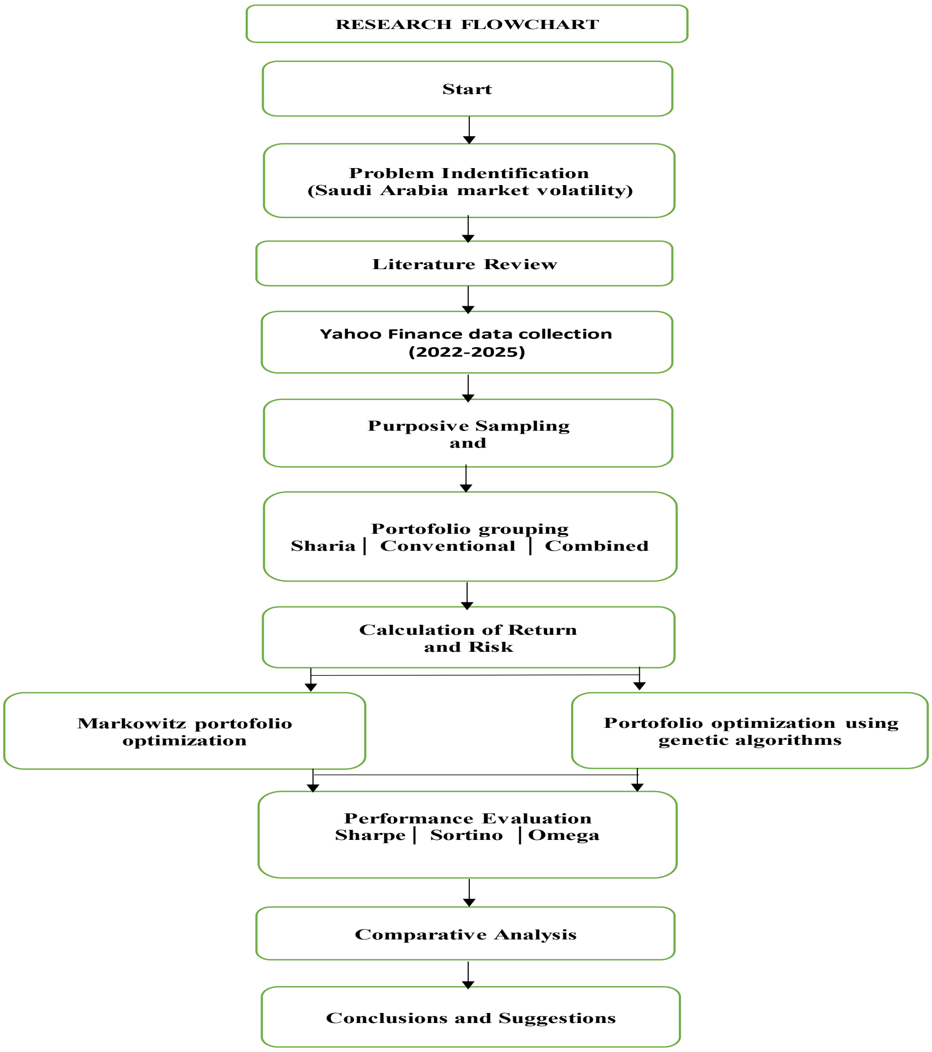

Figure 1 Research Flowchart

Through these stages, this study aims to produce a comprehensive comparative analysis of the risk and return efficiency of the two optimization methods.

4. Results and Discussion

Portfolio analysis in this study reveals a trade-off relationship between risk and expected re-turn across conventional stocks, Sharia-compliant stocks, and combinations of both in the Saudi Arabian stock market. Optimization was performed using the Markowitz Efficient Frontier method and the Genetic Algorithm implemented via Python to generate optimal portfolio combi-nations based on risk and return levels. The optimization process yielded a set of efficient portfolios visualized as an efficient frontier curve, enabling an analysis of the risk-return relationship patterns associated with each method. The resulting efficient frontier curves demonstrate that the Markowitz method forms a more structured frontier pattern based on the mean-variance approach, whereas the Genetic Algorithm produces a more flex-ible frontier due to its ability to explore a broader solution space. These findings indicate that the Genetic Algorithm possesses greater adaptability in handling the characteris-tics of the Saudi Arabian stock market, which tends to be volatile and influ-enced by oil price dynamics and global investor activity. Differences in the frontier characteristics of the two methods indicate that each approach pos-sesses a distinct level of efficiency in generating optimal port-folios. Portfolios situated on the left side of the efficient frontier curve represent asset combi-nations with minimum risk, whereas those on the right side indicate combi-nations offering higher expected returns accompanied by increased risk. In this study, the Genetic Algorithm generated a more diverse range of portfolio combinations compared to the Markowitz method, thereby offering investors a broader array of investment solutions. Heuristic ap-proaches based on Genetic Algorithms are more effective at solving portfolio optimiza-tion problems characterized by complex, non-linear solution spaces.

Portfolio performance was evaluated using the Sharpe Ratio, Sortino Ratio, and Omega Ratio to obtain a more comprehensive assessment. The Sharpe Ratio measures excess return rela-tive to total portfolio risk, thereby indicating general investment efficiency. Meanwhile, the Sortino Ratio evaluates down-side risk, making it more relevant for illustrating potential losses during vola-tile market conditions. Additionally, the Omega Ratio compares the distribu-tion of gains and losses against a specific target return, providing a broader evaluative perspective than the traditional mean-variance approach. The use of these three ratios demonstrates that portfolio performance assessment de-pends not only on return levels and total risk but also takes into account the stability and distribution of returns generated by each optimization method.

The research findings indicate that there is no single portfolio that is abso-lutely the best; rather, there is a set of efficient portfolios from which investors can choose based on their risk preferences. Risk-averse investors tend to select portfolios on the left side of the frontier, characterized by lower volatility, whereas investors with higher risk tolerance opt for portfo-lios on the right side, offering higher potential returns. In the dynamic context of the Saudi Arabian stock market, the use of a Genetic Algorithm offers an advantage by generating more adaptive portfolio solutions compared to the Markowitz method, par-ticularly when navi-gating changing market conditions and non-linear stock movement patterns. Consequently, combining modern optimization ap-proaches with performance evaluations based on the Sharpe, Sortino, and Omega ratios serves as an effective alternative for supporting investment de-cision-making in the Saudi Arabian stock market. These results align with the study by [8], which demonstrated that evolutionary algorithm approaches can generate more flexible port-folio combinations in markets characterized by high volatility and unstable return relation-ships.

4.1. Sharia-Only Group

Table 3. Optimal Stock Composition of the Sharia-Only Group

Syariah Only	5 Maximum Expected Return					5 Minimum Variance				
	Weight									
1020.SR	0,00%	0,00%	0,00%	0,00%	0,30%	0,30%	4,39%	8,48%	12,57%	16,67%
2280.SR	0,00%	0,00%	0,00%	0,00%	1,51%	1,51%	5,30%	9,09%	12,88%	16,67%
3020.SR	0,00%	0,00%	0,00%	2,82%	9,47%	9,47%	11,27%	13,07%	14,87%	16,67%
1030.SR	0,00%	1,36%	11,02%	18,18%	19,92%	19,92%	19,10%	18,29%	17,48%	16,67%
1120.SR	0,02%	15,44%	20,85%	24,44%	24,17%	24,17%	22,29%	20,42%	18,54%	16,67%
1140.SR	99,98%	83,20%	68,13%	54,56%	44,64%	44,64%	37,64%	30,65%	23,66%	16,67%
Expected Return	0,04%	0,04%	0,04%	0,03%	0,03%	0,03%	0,03%	0,03%	0,03%	0,02%
Standard Deviation	1,86%	1,70%	1,55%	1,42%	1,30%	1,30%	1,23%	1,17%	1,12%	1,09%
Coefficient of Variation (CV)	46,7462	45,0721	43,4413	42,0637	41,0747	41,0747	41,6037	42,5263	43,9905	46,1973
Sharpe	0,0214	0,0222	0,0230	0,0238	0,0243	0,0243	0,0240	0,0235	0,0227	0,0216
Sortino	0,0308	0,0319	0,0332	0,0343	0,0351	0,0351	0,0347	0,0339	0,0327	0,0311
Omega	1,05508635	1,057189948	1,059399454	1,061403418	1,062927622	1,062927622	1,062103109	1,060715596	1,058636549	1,055758851

Table 3 presents the optimal portfolio compositions for the Sharia-only group generated us-ing the Markowitz Efficient Frontier and Genetic Algorithm. The maximum-return portfolio achieved an expected return of 0.04% with a portfolio risk of 1.86%, while the minimum-variance portfolio reduced the portfolio risk to 1.09% with an expected return of 0.02%. Furthermore, the highest Sharpe Ratio (0.0243), Sortino Ratio (0.0351), and Omega Ratio (1.0629) were obtained by portfolios with moderate risk levels, indicating a more favorable risk-adjusted performance than portfolios targeting either maximum return or minimum var-iance.

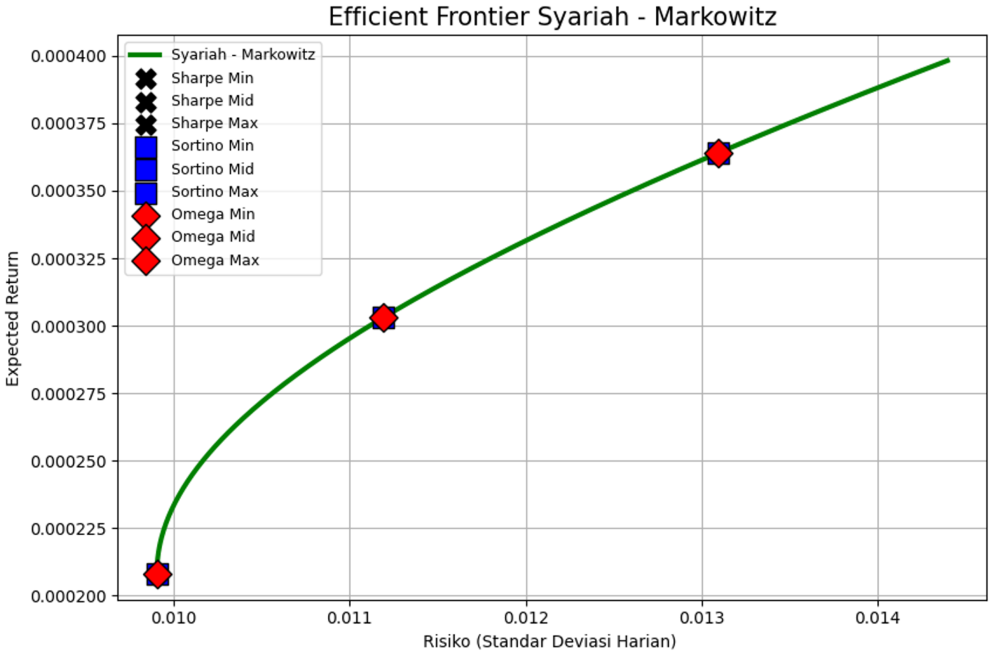

Figure 2. Sharia-Compliant Efficient Frontier (Markowitz Method)

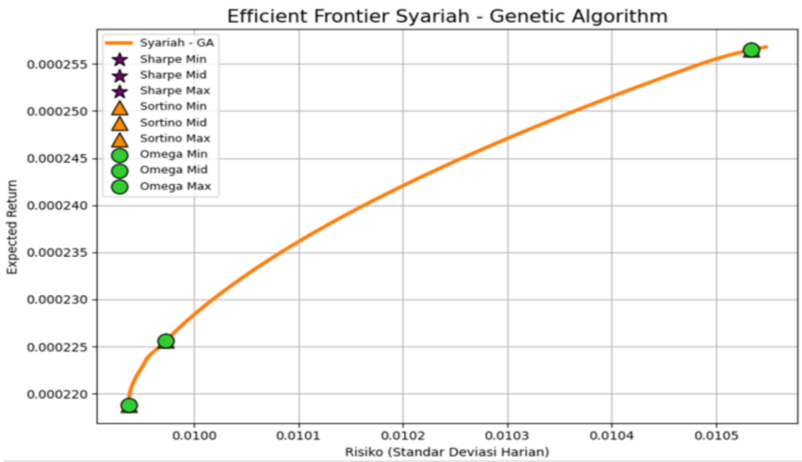

Figure 3. Efficient Frontier for Sharia-Compliant Stocks Using the Genetic Algorithm Method

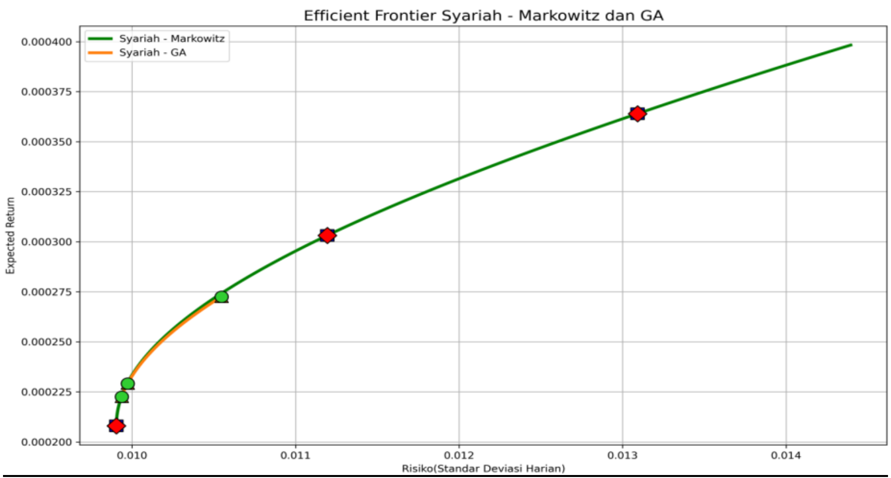

Figure 4. Efficient Frontier for Combined Sharia-Compliant Stocks Markowitz and Genetic Algorithm Methods

Figures 2–4 show the generated by the Markowitz and the Genetic Algorithm for a Sharia-compliant portfolio. Both methods exhibit the expected positive relationship between portfolio risk and expected return, confirming the fundamental principle of Modern Portfolio Theory proposed by [14]. The Markowitz model generated portfolios with higher expected returns accompanied by greater portfolio risk, whereas the Genetic Algorithm produced more stable portfolio allocations with a narrower range of portfolio risk. These findings are consistent with [10], who reported that evolutionary optimization methods improve portfolio robustness under uncertain market conditions, and with [11], who demonstrated that evolutionary optimization enhances portfolio diversification while maintaining competitive returns. Therefore, the Genetic Algorithm represents a practical alternative for constructing Sharia-compliant portfolios in dynamic market environments. These findings are consistent with [24], who demonstrated that the Genetic Algorithm is capable of identifying more efficient portfolio allocations within the mean–variance framework, resulting in improved risk-adjusted performance compared with conventional optimization approaches

4.2 Conventional-Only Group

Table 4. Optimal Stock Composition of the Conventional-Only Group

Conventional Only	5 Maximum Expected Return					5 Minimum Variance				
	Weight									
2150.SR	0,00%	0,00%	0,00%	2,15%	5,05%	5,05%	7,96%	10,86%	13,76%	16,67%
1060.SR	0,00%	0,00%	0,14%	3,25%	5,93%	5,93%	8,62%	11,30%	13,99%	16,67%
1010.SR	0,00%	0,00%	4,74%	7,03%	8,96%	8,96%	10,89%	12,81%	14,74%	16,67%
4130.SR	0,00%	15,61%	23,25%	22,24%	21,12%	21,12%	20,00%	18,88%	17,76%	16,67%
2270.SR	0,00%	41,07%	35,40%	32,22%	29,12%	29,12%	26,01%	22,90%	19,79%	16,67%
1810.SR	100,00%	43,32%	36,47%	33,11%	29,82%	29,82%	26,53%	23,25%	19,96%	16,67%
Expected Return	0,08%	0,07%	0,07%	0,06%	0,06%	0,06%	0,05%	0,05%	0,04%	0,04%
Standard Deviation	1,79%	1,32%	1,37%	1,32%	1,27%	1,27%	1,24%	1,21%	1,19%	1,19%
Coefficient of Variation (CV)	23,6206	18,4643	20,4856	21,0672	21,8849	21,8849	23,0140	24,5561	26,6488	29,4947
Sharpe	0,0423	0,0542	0,0488	0,0475	0,0457	0,0457	0,0435	0,0407	0,0375	0,0339
Sortino	0,0619	0,0800	0,0718	0,0697	0,0670	0,0670	0,0636	0,0595	0,0547	0,0493
Omega	1,111960744	1,145412528	1,130169293	1,126357196	1,121360112	1,121360112	1,115075604	1,107474044	1,098631017	1,088704116

Table 4 presents the optimal portfolio compositions for the conventional-only group generated using the Markowitz Efficient Frontier and Genetic Algorithm. The maximum-return portfolio achieved an expected return of 0.08% with a portfolio risk of 1.79%, whereas the minimum-variance portfolio reduced the portfolio risk to 1.19% while maintaining an expected return of 0.04%. Furthermore, the highest Sharpe Ratio (0.0542), Sortino Ratio (0.0800), and Omega Ratio (1.1454) were obtained by portfolios with moderate risk levels, indicating that balanced portfolios provided superior risk-adjusted performance compared with portfolios focusing solely on return maximization or risk minimization.

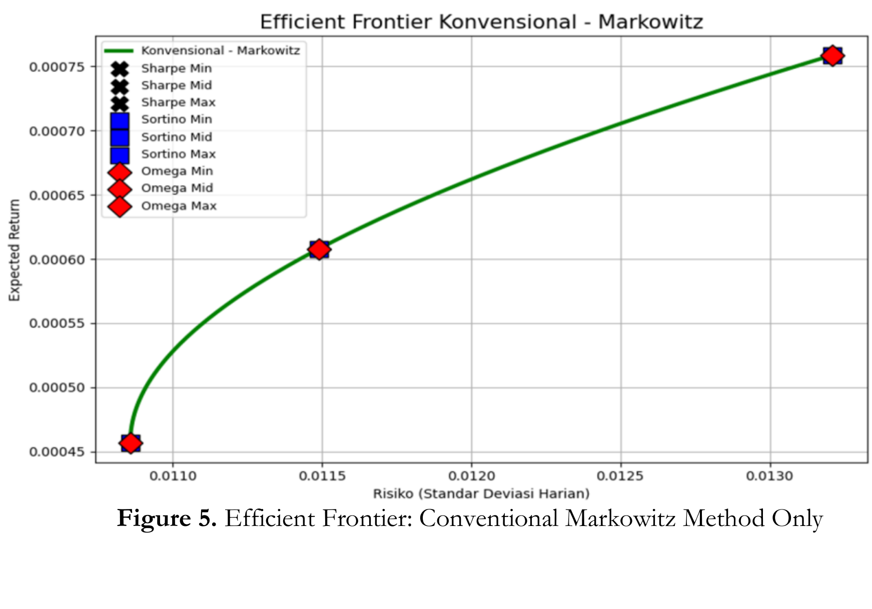

Figure 5. Efficient Frontier: Conventional Markowitz Method Only

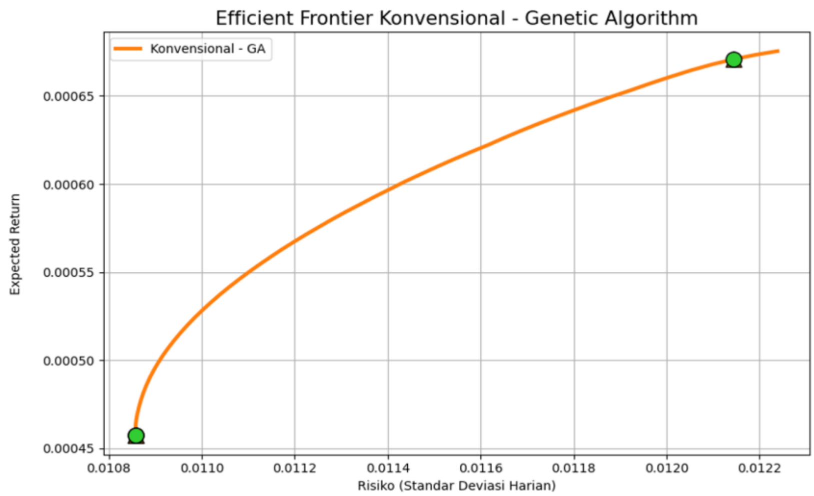

Figure 6. Efficient Frontier for Conventional Portfolios Using the Genetic Algorithm Method

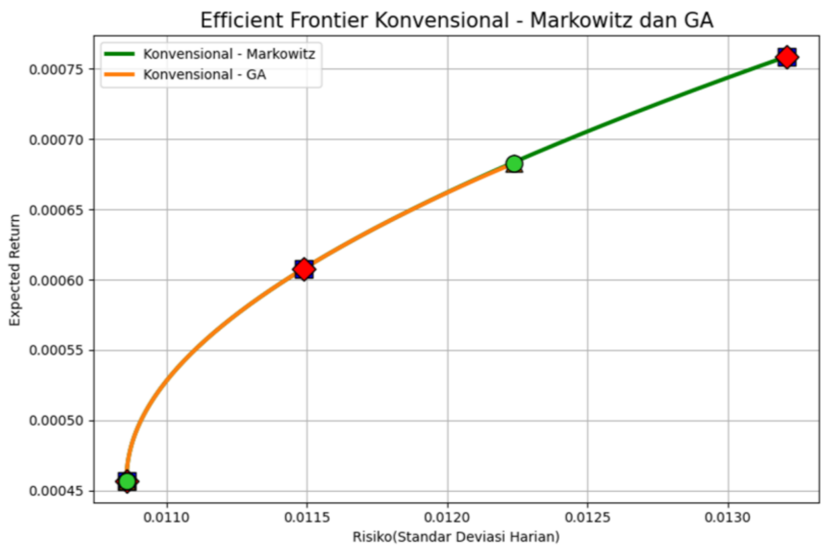

Figure 7. Efficient Frontier for Conventional Stocks: Markowitz vs. Genetic Algorithm

Figures 5–7 illustrate the results for a portfolio consisting solely of conventional assets, using both the Markowitz approach and the Genetic Algorithm. Both methods demonstrate a positive relationship between expected return and portfolio risk; however, the Markowitz model yields a more efficient outcome, offering the potential for higher returns at the cost of increased portfolio volatility. In contrast, the Genetic Algorithm generated portfolios with more consistent risk profiles and balanced asset allocations. These findings are consistent with [28], who concluded that the Markowitz framework remains effective for maximizing expected returns when market parameters are estimated accurately, while evolutionary optimization techniques provide greater flexibility and robustness under uncertain market conditions. Consequently, investors seeking higher returns may prefer the Markowitz approach, whereas those prioritizing portfolio stability may benefit from the Genetic Algorithm. This result is in line with [20], who emphasized that portfolio optimization should consider both return and risk-adjusted performance measures, as portfolios with lower volatility may provide superior investment efficiency despite offering slightly lower expected returns.

4.3 Combined Group

Table 5. Optimal Stock Composition of the Combined Group

Combination	Maximum Expected Return					Minimum Variance				
	Weight									
1020.SR	0,00%	0,00%	0,00%	0,00%	1,89%	1,89%	3,50%	5,11%	6,72%	8,33%
2280.SR	0,00%	0,00%	0,00%	0,00%	2,15%	2,15%	3,69%	5,24%	6,79%	8,33%
3020.SR	0,00%	0,00%	0,00%	2,03%	3,81%	3,81%	4,94%	6,08%	7,21%	8,33%
1030.SR	0,00%	0,00%	1,41%	4,87%	5,99%	5,99%	6,58%	7,17%	7,75%	8,33%
1120.SR	0,00%	0,00%	2,99%	6,02%	6,88%	6,88%	7,24%	7,61%	7,97%	8,33%
1140.SR	0,00%	2,58%	10,63%	11,58%	11,15%	11,15%	10,45%	9,74%	9,03%	8,33%
2150.SR	0,00%	0,00%	0,00%	0,00%	0,10%	0,10%	2,16%	4,22%	6,27%	8,33%
1060.SR	0,00%	0,00%	0,00%	0,00%	0,95%	0,95%	2,79%	4,64%	6,49%	8,33%
1010.SR	0,00%	0,00%	0,00%	2,12%	3,88%	3,88%	4,99%	6,10%	7,22%	8,33%
4130.SR	0,00%	16,26%	18,72%	17,47%	15,68%	15,68%	13,84%	12,00%	10,16%	8,33%
2270.SR	0,00%	39,55%	32,51%	27,51%	23,42%	23,42%	19,65%	15,88%	12,11%	8,33%
1810.SR	100,00%	41,61%	33,73%	28,40%	24,10%	24,10%	20,16%	16,22%	12,28%	8,33%
Expected Return	0,08%	0,07%	0,06%	0,06%	0,05%	0,05%	0,05%	0,04%	0,04%	0,03%
Standard Deviation	1,79%	1,30%	1,25%	1,18%	1,11%	1,11%	1,06%	1,03%	1,01%	1,00%
Coefficient of Variation (CV)	2362,06%	1853,12%	1931,94%	1979,13%	2059,76%	2059,76%	2191,08%	2389,10%	2687,15%	3140,20%
Sharpe	0,0423	0,0540	0,0518	0,0505	0,0485	0,0485	0,0456	0,0419	0,0372	0,0318
Sortino	0,0619	0,0797	0,0763	0,0744	0,0714	0,0714	0,0670	0,0612	0,0542	0,0462
Omega	1,1120	1,1449	1,1385	1,1350	1,1294	1,1294	1,1212	1,1106	1,0978	1,0831

Table 5 presents the optimal portfolio compositions for the combined portfolio consisting of Sharia-compliant and conventional stocks. The maximum-return portfolio achieved an expected return of 0.08% with a portfolio risk of 1.79%, whereas the minimum-variance portfolio reduced the portfolio risk to 1.00% while maintaining an expected return of 0.03%. Moreover, the highest Sharpe Ratio (0.0540), Sortino Ratio (0.0797), and Omega Ratio (1.1449) were obtained by portfolios with moderate risk levels, indicating that a balanced allocation of Sharia and conventional stocks provides superior risk-adjusted performance compared with portfolios emphasizing only maximum return or minimum variance.

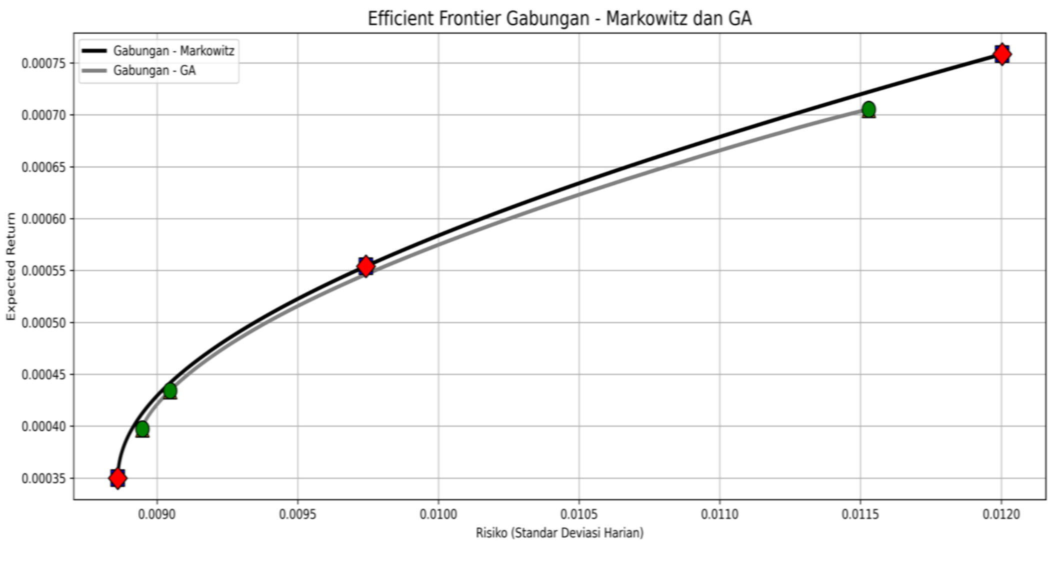

Figure 8. Combined Efficient Frontier

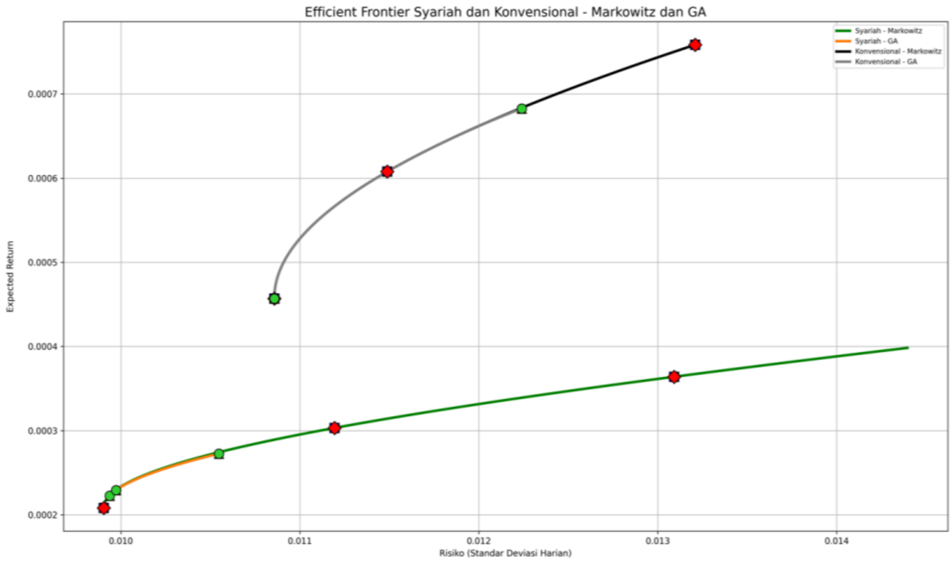

Figure 9. Efficient Frontier Comparison

Figures 7 and 8 demonstrate that combining Sharia-compliant and conventional stocks expands the feasible investment set and improves portfolio diversification under both optimization methods. The Markowitz Efficient Frontier generated portfolios with relatively higher expected returns but also higher levels of portfolio risk, whereas the Genetic Algorithm produced more balanced asset allocations with lower portfolio volatility. These findings are consistent with [6], who reported that meta-heuristic optimization techniques are effective in exploring broader solution spaces and generating portfolios with improved risk-adjusted performance compared with conventional optimization approaches. Therefore, integrating Sharia and conventional stocks provides investors with greater flexibility in constructing portfolios that balance expected return and investment risk. This finding supports [2], who argued that portfolio optimization in dynamic financial markets requires optimization techniques capable of accommodating uncertainty and complex interactions among assets. The balanced risk–return characteristics observed in the combined portfolio indicate that diversification across Sharia and conventional stocks enhances portfolio efficiency under the Genetic Algorithm approach.

4.4 Comparative Analysis of Portfolio Optimization Results

Provide a clearer comparison across the three portfolio groups, the main findings of the portfolio optimization results are summarized in Table 6. This summary consolidates the performance of the Markowitz Efficient Frontier and the Genetic Algorithm, thereby reducing repetition in the presentation of the results while highlighting the key differences between the two optimization methods.

Table 6. Comparative Summary of Portfolio Optimization Results

Portfolio Group	Markowitz	Genetic Algorithm	Comparative Findings
Sharia Portfolio	Higher expected return with relatively higher portfolio risk	Lower portfolio risk and more stable asset allocation	The Genetic Algorithm demonstrated superior risk management, whereas the Markowitz model emphasized return maximization.
Conventional Portfolio	Higher expected return accompanied by greater portfolio volatility	Lower portfolio risk with competitive expected returns	Both methods produced efficient portfolios, although their performance depended on investors' risk preferences.

Combined Portfolio	Greater diversification benefits and higher return potential	More balanced portfolio allocation with controlled portfolio risk	Portfolio diversification enhanced optimization efficiency under both optimization methods.

As summarized in Table 6, both the Markowitz Efficient Frontier and the Genetic Algorithm successfully generated efficient portfolios across all portfolio groups, although each method exhibited distinct optimization characteristics. The Markowitz Efficient Frontier consistently produced portfolios with higher expected returns, reflecting its objective of maximizing portfolio performance under the mean-variance framework. However, these higher returns were generally accompanied by increased portfolio risk. Conversely, the Genetic Algorithm generated portfolios with relatively lower risk and more balanced asset allocations, demonstrating its capability to explore alternative portfolio compositions that improve risk control while maintaining competitive expected returns.

The empirical findings are consistent with recent studies emphasizing the advantages of evolutionary optimization in portfolio management. [10] reported that the Genetic Algorithm is capable of generating more robust portfolio allocations under uncertain market conditions by balancing expected returns and portfolio risk more effectively than conventional optimization approaches. [11] demonstrated that evolutionary multi-objective optimization produces more diversified portfolios while maintaining competitive investment performance. The present study supports these findings, as the Genetic Algorithm consistently generated portfolios with lower volatility and more stable risk-adjusted performance across the Sharia, conventional, and combined portfolio groups.

Conversely, the higher expected returns achieved by the Markowitz Efficient Frontier are in line with the systematic review conducted by [28], which concluded that the mean-variance framework remains highly effective when portfolio parameters, particularly expected returns and covariance matrices, can be estimated accurately. However, the findings of this study also confirm that the superior return generated by the Markowitz model is generally accompanied by higher portfolio risk. This trade-off suggests that the Markowitz approach is more suitable for investors with higher risk tolerance, whereas the Genetic Algorithm offers a more conservative alternative for investors prioritizing portfolio stability.

Furthermore, the comparative analysis indicates that the combined portfolio achieved superior diversification benefits compared with the individual Sharia and conventional portfolios. The integration of Sharia-compliant and conventional stocks expanded investment opportunities and improved portfolio efficiency under both optimization methods. These findings indicate that portfolio diversification remains an effective strategy for reducing portfolio risk while maintaining competitive expected returns, particularly in dynamic markets such as the Saudi Arabian stock market.

Overall, the findings demonstrate that neither optimization method can be regarded as universally superior. Instead, the choice of optimization technique should be aligned with investors' objectives, risk tolerance, and prevailing market conditions. The Markowitz model remains appropriate for investors seeking maximum expected returns despite higher volatility, whereas the Genetic Algorithm provides a more flexible and stable portfolio optimization framework under uncertain market environments. Therefore, the two methods should be viewed as complementary approaches rather than competing alternatives in modern portfolio management.

4.5 Research Limitations

This study has several limitations that should be acknowledged. First, the analysis only included twelve selected stocks listed on the Tadawul All Share Index (TASI), consisting of six Sharia-compliant and six conventional stocks selected using the Coefficient of Variation. Consequently, the findings may not fully represent the overall Saudi Arabian stock market. Second, portfolio optimization was performed using only the Markowitz Efficient Frontier and the Genetic Algorithm. Other optimization approaches, such as Particle Swarm Optimization, Differential Evolution, or Deep Reinforcement Learning, were not examined and may produce different optimization outcomes. Third, this study employed historical daily stock prices during the observation period and did not explicitly consider macroeconomic variables, geopolitical events, or transaction costs that may influence portfolio performance. Future studies are therefore encouraged to incorporate broader datasets, additional optimization techniques, and external market factors to improve the robustness and practical applicability of portfolio optimization models.

5. Conclusions

Based on the study comparing the Markowitz Efficient Frontier method and the Genetic Algorithm for constructing optimal Saudi Arabian stock portfolios, both methods were found capable of generating efficient portfolio combina-tions with distinct risk-return characteristics. The Markowitz method tends to yield a higher maximum expected return, albeit accompanied by greater vola-tility. In contrast, the Genetic Algorithm produces portfolios with relatively lower and more stable risk levels, owing to its ability to explore asset combi-nations with greater flexibility. The findings also indicate that conventional stock portfolios offer higher return potential and performance ratios compared to Sharia-compliant stock portfolios, despite carrying higher risk. Evaluations using the Sharpe, Sortino, and Omega ratios reveal that portfolios with moderate risk levels tend to achieve more optimal risk-return efficiency than those targeting maximum returns or minimum risk. Under the Markowitz method, the maximum Sharpe Ratio for conventional portfolios reached 0.0574 with an Omega Ratio of 1.1548, whereas the Genetic Algorithm yielded a maximum Sharpe Ratio of 0.0558 and an Omega Ratio of 1.1501. Conversely, Sharia-compliant stock portfolios demonstrated lower risk levels but generated relatively lower expected returns and performance ratios compared to conven-tional portfolios. These results demonstrate that both stock characteristics and optimization methods influence the construction of optimal portfolios. Overall, the study indicates that the Markowitz method excels in generating maximum expected returns, while the Genetic Algorithm proves more adaptive in creating stable portfolio combinations amidst dynamic market conditions. Consequently, the choice of portfolio optimization method should be aligned with investor preferences regarding risk and expected returns. Furthermore, the use of the Python programming language for data processing and portfolio optimization has proven effective in enhancing analytical efficiency and facil-itating the visualization of research findings.

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