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Comparative Study of Gasoline Fuel Mixture to Reduce Emissions in the Metropolitan District

Vicente Rojas-Reinoso [1], Janko Alvarez-Loor [1], Henry Zambrano-Becerra [1] and José Antonio Soriano [2,*]

1 Laboratorio de Ingeniería Automotriz, Carrera de Ingeniería Automotriz-Campus Sur, Universidad Politécnica Salesiana, Av. Rumichaca & Av. Morán Valverde, Quito 170146, Ecuador

2 Instituto de Investigación Aplicada a la Industria Aeronáutica, Escuela de Ingeniería Industrial y Aeroespacial, Campus de Excelencia Internacional en Energía y Medioambiente, Universidad de Castilla-La Mancha, Av. Carlos III, s/n, 45071 Toledo, Spain

* Correspondence: joseantonio.soriano@uclm.es

Abstract: In the present investigation, the behavior of fuel consumption was studied due to the high cost of gasoline and its price increase in Ecuador in recent years, for which reason the different mixtures have been studied to obtain lower consumption. The optimum fuel mixture rate for a T18SED e-tec II engine, Multiport Electronic Fuel Injection System (MPFI) between extra gasoline, super gasoline, and ethanol was obtained on two urban roads in the city of Quito (Ecuador). For the first test, mixtures of 10% super gasoline and 90% extra gasoline were made, and so on, for the following tests: (20–80), (30–70), (40–60), (50–50), (60–40), (70–30), (80–20), and (90–10) % super and extra gasoline. Then, mixtures between super gasoline and ethanol and extra gasoline and ethanol with concentrations of 5% and 10% were made. The results showed a low consumption on Maldonado Avenue with the 20% extra and 80% super mixtures obtaining a value of 2.9 L, while the mixture that presented a higher consumption was 100% extra of 3.4 L. At the end of each test, the fuel tank was completely drained, and the engine control unit (ECU) was reset for each test. The data acquisition was carried out through an OBD II (on-board diagnostic system) installed in each of the tests.

Keywords: fuel mixture; ethanol; super gasoline; extra gasoline; emissions; urban roads; real driving

Citation: Rojas-Reinoso, V.; Alvarez-Loor, J.; Zambrano-Becerra, H.; Soriano, J.A. Comparative Study of Gasoline Fuel Mixture to Reduce Emissions in the Metropolitan District. *Sustainability* **2023**, *15*, 2921. https://doi.org/10.3390/su15042921

Academic Editor: Barry D. Solomon

Received: 2 January 2023
Revised: 26 January 2023
Accepted: 28 January 2023
Published: 6 February 2023

1. Introduction

Climate change has led to a considerable increase in pollutant emissions in all countries, causing environmental changes in all countries, CO_2 emissions must decrease by 45% by 2030 and go down to zero generation by 2050 [1]. Ecuador has not been exempt from this, causing a change in the winters of the regions of the country, increasing its average temperature from 0.5 to 1 degree Celsius [2]. One solution is the reduction in polluting gases, improving the properties of the fuels, incorporating additives, oxygenating the fuel with ethanol, and/or mixing the fuels. In Ecuador, there is no technical support that explains when fuels are mixed and what their effects are on the efficiency of an internal combustion engine [3]. In the present research, the objectives were to analyze the fuel mixtures according to the octane characteristics, focusing on the review study framework according to the most optimal performance of the engine and its energy performance. This is because the cost of fuel in Ecuador has increased, and the technology of spark ignition vehicles are electronic injection of the third and fourth generations, which are most of the rolling vehicle fleet.

Mixing fuels produces changes in their properties, as occurred in the study of Guzmán et al. [3] where the performance of an Otto engine was analyzed by making mixtures of extra and super gasoline, having percentages of mixtures between 30% and 50% of extra, and 50% and 70% of super. As evidenced in Table 1, the following results were obtained: the mixtures of 50% extra and super had an increase in maximum power of 81.3 HP; on the other hand, super gasoline reached an increase in torque of 120.92 Nm, and the mixture of 70% super and 30% extra had a low torque of 117.14 Nm. The characteristics of the work and performance with vehicles on the road must be improved to check the behavior of the mixtures made, thus we compared the results obtained by Guzmán, as shown in Table 1.

Table 1. Torque and power values in the fuel mixtures.

Mixtures	Power (HP)	Torque (Nm)
Extra	77.6	86.8
Super	79.4	89.2
50% Super and 50% Extra	81.3	86.4
70% Super and 30% Extra	79.9	86.6

When making mixtures, an increase in octane is also obtained, as shown in the investigation by Guzmán et al. [3]. In the research octane number (RON) tests, it was shown that super gasoline complies with the norm INEN 935 [4], as shown in Table 2. Regarding extra gasoline, the results showed that it contained 1.6 octane, lower than that established in the regulations. Instead, a new octane rating was generated in the 50% extra blends such as 88.8 super, and in the 70% super and 30% extra blends of 89.8. The most optimal mixture according to the operating characteristics of the combustion according to the number of RON is 70/30, but with respect to the economy, a 50/50 mixture is the most viable, decreasing the yield more, or more with respect to 100% super, but maintaining a considerable performance of combustion.

Table 2. Laboratory-acquired octane number (RON) values.

Combustibles	Research Octane Number (RON)
100% Extra	85.4
100% Super	92.0
50% Super and 50% Extra	88.8
70% Super and 30% Extra	89.8

According to what has been established by Eyidogan et al. [5], their research showed that ethanol fuel blends such as gasoline (E5, E10) and methanol-gasoline (M5, M10), resulted in an increase in fuel consumption when using ethanol, the specific consumption of fuel and octane. These results were as expected, since the calorific value of alcohols is between 37% and 53%, lower than that of gasoline. We analyzed the study of the percentage of ethanol and the additive stabilizers placed to maintain the optimal mixture, in addition to ensuring the use of a water-free alcohol, with a minimum purity of 98%. However, other methods used is by test benches to achieve the most accurate mixtures especially uniformity as it does Phuangwongtrakula et al. [6] which you use first apiece of equipment is an eddy current dynamometer which is used to acquire torque and power from the motor. The second equipment was removed to measure the air flow for consumption and the third was to analyze the air–fuel ratio, obtaining as a result, that an adequate proportion of the mixture of ethanol and gasoline improves the performance of the engine torque fundamentally at low revolutions, and ethanol provides a higher octane rating, which contributes to better detonation [7], allowing for a higher compression ratio in a MEP engine. It was obtained in the results that the optimal mixture of ethanol and gasoline fuel improved the torque performance at low speeds.

By conducting pressure variation analysis, Catapano et al. [8] implemented ethanol in percentages of 10%, 50%, and 85%, achieving as a result a better development in the engine, especially with E50, which generated a better performance in the injector for a vaporization of shorter duration. This allows one to characterize the mixing dosage and generate a mathematical prediction model such as Gomez et al. [9], who obtained stoichiometric ratios in a range from 0% to 100%, arriving at an equation derived from the mixture of ethanol and gasoline, and thus obtained exact results, showing that power, like torque, decreases when the division of the mole of ethanol increases. According to Castelo et al. [10], extra fuel and biofuel models from 5% to 10% ethanol were used in an indirect electronic injection ignition engine, with a cylinder capacity of 1.0, in which the gas emissions were analyzed at an atmospheric pressure of 72 kPa and at a height of 2700 m above sea level. In the Ecuadorian highlands, the tests were of power, emissions, and engine torque, resulting in an improvement in torque and power with the E10 fuel compared to E5 and extra, concluding that when oxygen is low, CO and HC polluting gases increase, which shows that the mixture is rich.

Lema [11] investigated the polluting sources from gas emissions, and verified the behavior in an internal combustion engine when implementing bioethanol with an E5 mixture, achieving a reduction of 30 to 40% of harmful gases. However, Suarez et al. [12] used an internal combustion engine, Jacto model, in order to thermodynamically evaluate the mixtures of ethanol and gasoline with different percentages of E10, E15, E20, and E25, suggesting, as a result, that when placing pure gasoline, high air and fuel ratios are generated. However, this was higher when ethanol mixtures of E10 and E15 were used, from which it was concluded that ethanol generates oxygen, but impoverishes the mixture and improves combustion quality. In the analysis carried out by Espinoza et al. [13], a mathematical model was generated that predicted the specific fuel consumption in a 1.4 Otto cycle engine when using gasoline mixtures by implementing densities at the same ethanol of 0, 25, 75, and 100% vol. However, Hsieh et al. [14] investigated the mixture of ethanol and gasoline with values of 0%, 5%, 10%, 20%, and 30% ethanol [8,15,16]. Implemented in a Nissan Sentra GA16DE engine, the experiment was based on speed variations ranging from 400 to 1000 rpm, having an air damper ranging from 0 to 100%, which resulted in an increase in the percentage of ethanol, causing a reduction in the calorific power value of fuels. Mixing ethanol and gasoline [17] increases the engine torque and specific consumption, and significantly limits the polluting emissions of CO and hydrocarbons.

In the article by Wu et al. [18], the similarity between the blend of ethanol and gasoline, and the air–fuel parity ratio on spark ignition engine performance was investigated. The experiment dealt with different fuel parity ratios ranging from −25 to 25% with a 5% increase. Tests were carried out with five fuels (E0, E5, E10, E20, and E30), the engine speed ranges were 3000 and 4000 rpm, six valves had openings from 0 to 100%, and one had a 20% increase. In the results, it was found that the highest torque output as specific heat consumption was achieved when the air–fuel ratio was slightly lower. More stable change variables of control (engine load, torque, power, air flow) must be focused on to ensure changes in the ethanol mixture dosage. Topgül et al. [19] showed that when using ethanol blends, it provides an increase in the compression ratios of engines without detonation. Bayraktar et al. [20] carried out research using gasoline–ethanol blends (1.5–12% by volume of ethanol, with an increase of 1.5) in terms of engine performance and emissions and achieved an increase in ethanol capacity, increasing the efficiency as well as power due to the mixture of fuels.

Ghazikhani et al. [21] investigated the results of ethanol with its additives in a performance ratio (5%, 10%, and 15%) as the engine emissions (HC, CO, CO_2, and NO_x) of two strokes when mixing gasoline and ethanol [22] and concluded that when using alcoholic fuels such as ethanol, it has a rapid evaporation, and the use of additives in ethanol also reduces the pollutants emitted by the engine, where CO had a reduction of 35%. However, nitrogen oxide emissions increase with increasing exhaust temperature, while hydrocarbons (HC) decrease by 30%. Nevertheless, Eyidogan et al. [5] investigated ethanol fuel blends such as gasoline (E5, E10) and methanol-gasoline (M5, M10), stating that the use of ethanol led to an increase in specific fuel consumption and octane rating. The results were as expected since the calorific value of alcohols is between 37% and 53% lower than that of gasoline. Can et al. [23] obtained results that showed that when increasing the ethanol, the emissions of SO_2, CO, and soot decreased noticeably, but there was an increase in the emissions of NO_x when placing 10% and 20% of ethanol [24].

Another of the conditions of focus was the analysis of the improvement in the quality of the fuels, increasing their calorific characteristics as well as their RON index, which allows one to reduce the generation of soot during combustion by up to 60% of the specific mass and 40% of the solid PN, showing that the ignition process is faster and closer to the upper dead center of the plunger, as indicated by Yusuf A. et al. [25], and that when placing mixture indices from 5 to 15% of ethanol, the performance was improved between 11.3% and 15.7%, power between 1.3% and 2.4%, and emissions reduction, since the characteristics of this fuel improved the reduction in soot in a stable range of operation between 1800 and 3000 rpm, as long as the environmental conditions and engine operating regimes remained stable [26]. Abdel-Rahman and Osman [27] analyzed the results by varying the compression ratio (8:1–13:1), when implementing different fuels such as ethanol and gasoline using (E10, E20, E30, and E40) [28]. Obtaining a high compression ratio and increasing power as a result of the tests, when the percentage of ethanol was greater than 20%, a compression ratio of 8:1 was obtained for E10, 10:1 for E20, 12:1, and for E30 and E40. Relative to the mean effective pressure, higher octane ethanol has a better compression ratio and higher engine efficiency. Ethanol has a higher calorific value of vaporization and allows the temperature of the air intake manifold to be reduced, increasing the density of the air, and achieving a greater mass of air in the cylinders.

Zafar et al. [29] showed, with the ANFIS and MORSM models, through a fractional distillation with the Box–Behnken technique, that by modifying the microalgae oil, it produces hydrocarbons with a similar boiling point range as fossil fuels, showing that the microalgae oil is a sustainable fuel that reduces greenhouse gas emissions in the aviation sector. Yodice and Cardone [30] investigated, through an experimental study, a comparison of the physicochemical properties of ethanol and gasoline by analyzing the reliability of ethanol as an alternative fuel for spark ignition engines. On the other hand, they focused on the impact of ethanol fuel as gasoline on the formation of CO and HC, showing that when adding ethanol with gasoline mixtures, the exhaust emissions of both CO and HC decreased in different operating conditions, but that there was also a greater amount of oxygen when implementing 20% ethanol, while in cold phases, there was a decrease in CO and HC compared to that of gasoline. A working system for fuel mixtures based on the principle of neurodifuse statistics (ANFIS) was carried out by Zafar et al. [27] to optimize the mixtures according to the interactive behavior of the combustion operation and engine performance, using biofuels that improve the boiling point of the base fuel.

The objective of the study was the combination of fuels to experimentally determine the optimal mixing ratio of fuels such as ethanol, super, and extra to maximize thermal efficiency through static tests, considering that the super fuel is more expensive than the extra as it also has a higher-octane rating.

2. Materials and Methods

2.1. Materials

2.1.1. Data Acquisition Card

For the development of this study, the data collection was generated by means of an on-board diagnostic card OBD II (KONNWEI KW902) as shown in Figure 1, responsible for monitoring all of the functional systems of the vehicle and also stores error codes referring to failures that the vehicle presents. The vehicle, which, through CAN communication, acquires the information flow in each test [31].

The operation of the KONNWEI ELM327 card allows for the measurement of fuel consumption such as supply voltage, temperature range, and many more functions as well as the throttle position, recording data in real-time.

The diagnostic connector or DLC (Data Link Connector) of the OBD II system is the one that allows for the connection with the reading system and must comply with the specifications of the ISO 15031-3:2004 standard. The DLC connector consists of 16 contacts.

Figure 1. OBD II (KONNWEI KW902).

2.1.2. Software

The Torque Pro OBD 2 Car software version 1.0.48 was installed, which is an application that allows for real-time analysis of the vehicle's performance, diagnoses errors of faults in the vehicle, and the software connects via Bluetooth with the device.

2.1.3. Vehicles

The test vehicle was a Chevrolet Optra with a T18SED engine [32]; the vehicle's technical data sheet with its specifications is shown in Table 3. It was verified that it was in the optimal operating conditions for the specific validation and reliability of the data.

Table 3. Technical sheet for the Chevrolet Optra.

Vehicle	Engine	Year	Compression Ratio	Torque (kg)	Power (HP)
Chevrolet Optra	T18SED	2008	9.8:1	17.40	122

This vehicle was chosen as it is a commercial vehicle in Quito. Preventive maintenance was carried out so that there were no alterations in the values obtained. The injectors were cleaned by ultrasound to avoid plugging in the nozzles of the injectors, thus cleaning the throttle body.

Table 4 shows the atmospheric boundary conditions, where the road tests of the city of Quito were carried out.

Table 4. Atmospheric boundary conditions in Quito (Ecuador).

City	Height	Average Temperature
Quito (Ecuador)	≈2850 m above sea level	17 °C

2.1.4. Fuel Tank

A smaller fuel tank than the original was designed, with the aim of using the necessary fuel for each test and not having fuel losses, as shown in Figure 2.

A fuel tank with such characteristics was used that was external to the original tank, which makes it easy to replace where it will be placed in the rear passenger seat to facilitate the extraction of fuel to carry out each road test. The tank was 5 gallons, since in preliminary tests, they determined that the fuel tank consumed 2 to 3 gallons on trips in a tank made of 5 gallons.

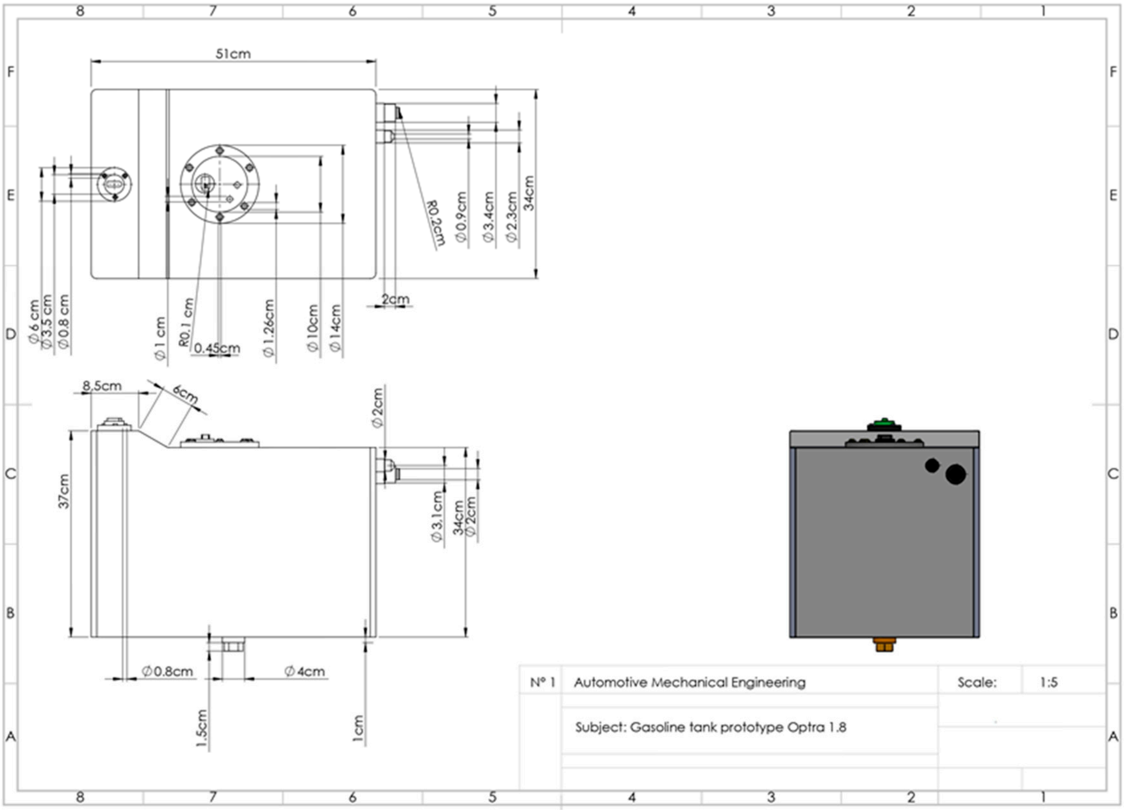

Figure 2. Fuel tank design.

2.1.5. Route

The tests were established on the two busiest roads in the city of Quito: Maldonado Avenue (Figure 3) and the Simón Bolívar Highway (Figure 4).

The Maldonado Avenue route was taken because it is a high-traffic road. The route starts from the beginning of Maldonado Avenue to the Villaflora roundabout, and returns, obtaining a total of 30 km [33].

As shown in Figure 4, the second route that was taken for data collection was the Simón Bolívar Highway, which has an average of 50,000 vehicles circulating every day. The section starts from the Guajaló Bridge to the "El Ciclista" roundabout, and has a section that is 60 km long. As shown in Table 5.

Figure 3. Maldonado Avenue.

Figure 4. Simón Bolívar Highway.

Table 5. Description of the routes.

Route	Distance [km]	Type
Maldonado Avenue from Cutulagua to the Villaflora roundabout	28.4	Avenue
Av. Simón Bolívar from the El Ciclista roundabout to the Guajaló Bridge	59.7	Highway
	88.1	Total

2.1.6. Fuels

Ecuador has three types of fuel: 92-octane super fuel, 85-octane extra fuel, and ecopaís gasoline, which is distributed in the country's coastal area and contains 5% ethanol [34].

The tests began with the 87-octane extra fuel and the 92-octane super fuel, purchased at the Primax gas station in the Metropolitan District of Quito, since this pump has the least particulate material in which percentage mixtures are made and placed in a single station in order to not present alterations in the data obtained.

The extra, super, and ethanol fuel blends were intended to analyze the optimal fuel blend as well as improve the fuel consumption and polluting emissions. Table 6 shows the physicochemical properties of the fuels under test.

Table 6. The physical and chemical properties.

Properties	Gasoline	Ethanol
Chemical formula	$C_5H_{10a}C_9H_{18}$	C_2H_5OH
Physical state	Liquid	Liquid
Molecular weight composition (wt%)	100–105	46
Carbon	85–88	52.2
Oxygen	0	34.7
Specific gravity (15.5 °C)	0.72–0.78	0.796
Boiling temperature	27–225	78
Freezing temperature (°C)	−40	−114
Reid vapor pressure (bar)	0.55–1.034	0.16
Calorific power (MJ/Kg)	44–47.3	27
Research octane number (Ecuador)	87–92	113

2.2. Methods

In the road tests carried out, the parameters of the vehicle, emissions, and fuel consumption were obtained. For each route, the corresponding fuel mixture was established with the objective of analyzing which mixture is ideal for greater efficiency and reduction in emissions. The following diagram (Figure 5) shows the methodology used in the experimental test schematically.

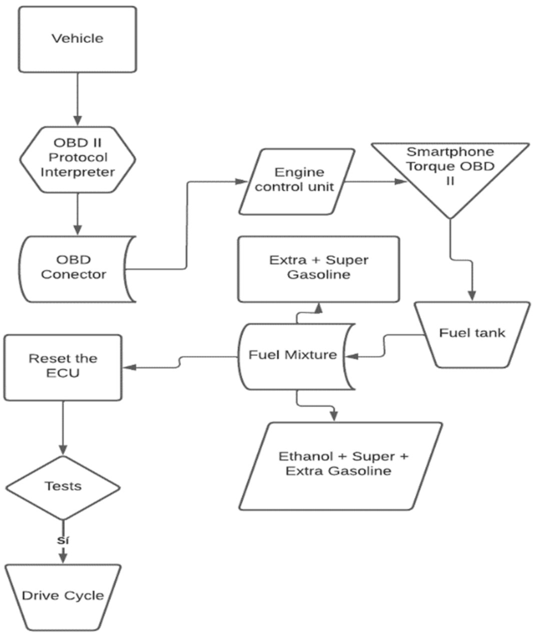

Figure 5. Methodology.

The vehicle carried out different route tests on the Simón Bolívar Highway and Maldonado Avenue during traffic hours to show consumption by obtaining the data in real-time through the ODB-II interface and the TORQUE Pro software to obtain data generated by the vehicle.

Driving cycles were carried out, and where the a driving style in the city and on the highway were represented considering the characteristics of the vehicle, traffic conditions, and climatic conditions, type of road, and driver profile.

For the tests, the NEDC driving cycle was established, which determines consumption in urban, extra-urban, and mixed routes.

EXTRA 87 octane fuel was used in the vehicle, while the super 92 octane fuel was used. In 2020, the price of the extra fuel had a cost of $1.75, while the super fuel had a cost of $2.28 according to Petroecuador.

In 2022, the price of extra fuel increased by $2.55 per gallon, and the price of super fuel was instead $5.20 per gallon, indicating that the super gallon increased by $0.34.

In each test that was carried out with the vehicle both on the road and on the avenue, the data obtained from the OBD II were saved in the application.

At the end of each test, the fuel tank was completely emptied, and the excess fuel was deposited in tanks for later measurement. The new mixture was placed in the tank, and this procedure was carried out for each mixture generated, while the module (ECU) of the vehicle was reset for each test in order to not have alterations with the generated values of the vehicle.

Once the tests between the mixture of super gasoline and extra gasoline were carried out, the mixtures between super gasoline and ethanol were made as well as the extra gasoline and ethanol with the following maximum percentages of ethanol: E5% and E10%.

A measurement of each fuel sample was performed, and dynamic tests were performed to obtain the following data: emission levels of unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2).

2.2.1. Driving Cycles

Driving cycles were carried out for the dynamic tests both on Maldonado Avenue and on Simón Bolívar Highway, taking into account the provisions of the Regulations to the Land Transport, Traffic and Road Safety Law of article 191 [35]. The maximum speed limit on Simón Bolívar Highway is 90 km/h and on Maldonado Avenue, it is 50 km/h.

Espinoza et al. [36] applied a statistical experimental model to obtain a specific value of fuel consumption directly according to the percentage of ethanol, which means that when the percentage of ethanol increases, the consumption of the engine is greater, and is due to the reduction in the calorific power in the mix with the change in ethanol concentration.

Castelo et al. [10] implemented the experimental methodology with longitudinal design in data collection at different intervals in terms of time and conditions.

Gomez et al. implemented a mathematical model [9,13] and obtained stoichiometric ratios ranging from 0 to 100%, establishing an equation derived from the mixture of ethanol and gasoline and achieving the exact results.

2.2.2. Uncertainty Analysis

An uncertainty analysis was performed with the dispersion of data obtained in the route tests to generate an equation of the fuel consumption behavior and the calculation of injection system emissions. Minitab software was used for the analysis of variance, which was less than 30%, which is why a statistical analysis of results with value tables obtained in the tests was generated.

According to the speed regulations of the transit agency of Ecuador, the tests carried out with a real driving cycle were obtained through the communication interface of the data of the CAN network to determine the measured values in the five tests carried out by each route, in order to generate a robust database and thus able to reduce the error factor and its uncertainty.

The established driving cycles were carried out in a stable manner and in similar traffic conditions, thus allowing us to maintain the measurement data for the generation of the statistical results to be presented.

3. Results

Table 7 shows the data of the mixtures made on Maldonado Avenue, where the engine load, fuel consumption in liters, and CO_2 emissions can be seen.

Table 7. Fuel mixtures for Maldonado Avenue.

Mixture	Engine Load (%)	CO_2 (g/km)	Consumption (L/100 km)	Consumption in Route (L/30 km)
100% Extra	9.461	174.957	0.795	3.432
100% Super	10.620	179.801	0.350	3.050
90% Extra and 10% Super	10.115	185.366	0.211	3.252
80% Extra and 20% Super	10.262	186.310	0.258	3.154
70% Extra and 30% Super	9.944	172.832	0.169	3.411
60% Extra and 40% Super	10.330	161.871	0.171	2.923
50% Extra and 50% Super	10.301	171.548	0.217	2.645
40% Extra and 60% Super	9.518	153.222	0.141	2.654
30% Extra and 70% Super	9.285	168.040	0.140	2.754

Table 7. *Cont.*

Mixture	Engine Load (%)	CO_2 (g/km)	Consumption (L/100 km)	Consumption in Route (L/30 km)
20% Extra and 80% Super	9.724	144.816	0.152	2.921
10% Extra and 90% Super	9.626	169.772	0.160	2.712

Table 8 shows the data of the mixtures made on Simón Bolivar Highway, where the engine load, fuel consumption in liters and CO_2 emissions can be seen.

Table 8. Fuel mixtures for the Simón Bolívar Highway.

Mixture	Engine Load (%)	CO_2 (g/km)	Consumption (L/100 km)	Consumption in Route (L/60 km)
100% Extra	21.478	226.854	0.113	5.421
100% Super	23.181	238.371	0.096	4.932
90% Extra and 10% Super	23.148	232.598	0.075	4.254
80% Extra and 20% Super	22.501	199.946	0.068	4.456
70% Extra and 30% Super	22.258	200.149	0.062	4.654
60% Extra and 40% Super	21.395	203.462	0.057	5.154
50% Extra and 50% Super	22.780	213.660	0.085	5.323
40% Extra and 60% Super	21.043	208.001	0.053	4.851
30% Extra and 70% Super	23.530	202.225	0.049	4.126
20% Extra and 80% Super	23.157	197.581	0.053	3.91
10% Extra and 90% Super	23.755	202.769	0.043	4.554

Table 9 shows the data of the mixtures with ethanol made on the Simón Bolivar Highway, where the engine load, fuel consumption in liters, and CO_2 emissions can be seen.

Table 9. Fuel mixtures/ethanol for the Simón Bolívar Highway.

Mixture	Engine Load (%)	CO_2 (g/km)	Consumption (L/100 km)	Consumption in Route (L/60 km)
95% Extra and 5% Ethanol	24.696	200.178	0.041	5.1
90% Extra and 10% Ethanol	23.555	192.521	0.039	4.40

Table 9. *Cont.*

Mixture	Engine Load (%)	CO_2 (g/km)	Consumption (L/100 km)	Consumption in Route (L/60 km)
95% Super and 5% Ethanol	25.614	216.459	0.037	4.50
90% Super and 10% Ethanol	24.932	231.912	0.035	4.60

Figures 6 and 7 show the fuel consumption obtained in liters for each of the percentage mixtures with respect to the engine load carried out on Maldonado Avenue and on the Simón Bolívar Highway.

The fuel consumption values obtained for 100% extra on both routes were higher than all the mixtures due to their low octane rating.

The consumption data obtained on Maldonado Avenue are indicated in the following chronological order: from highest to lowest consumption: 100% extra, 70% extra and 30% super, 90% extra and 10% super, 80% extra and 20% super, 100% super, 60% extra and 40% super, 20% extra and 80% super, 30% extra and 70% super, 10% extra and 90% super, 60% extra and 40% super, 40% extra and 60% super, and 50% extra and 50% super, and the load values varied between 1.44%, which makes these data irrelevant in Maldonado Avenue.

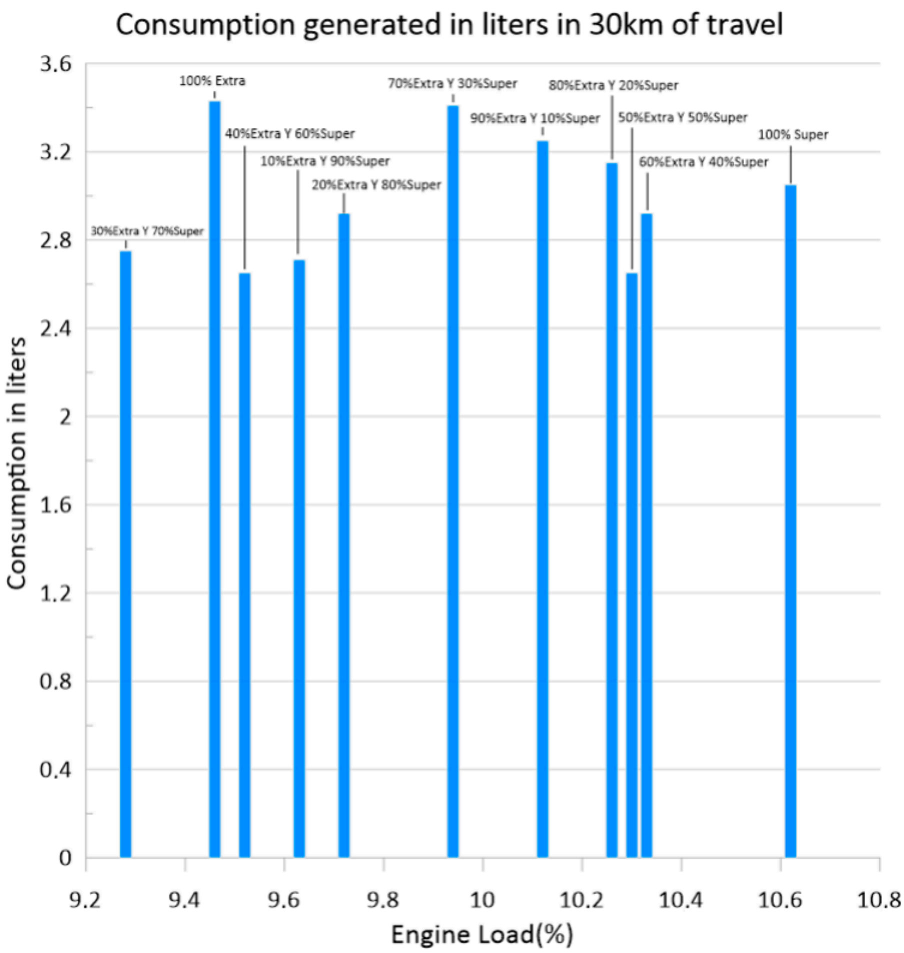

Figure 6. Gasoline consumption for 30 km of travel on Maldonado Avenue.

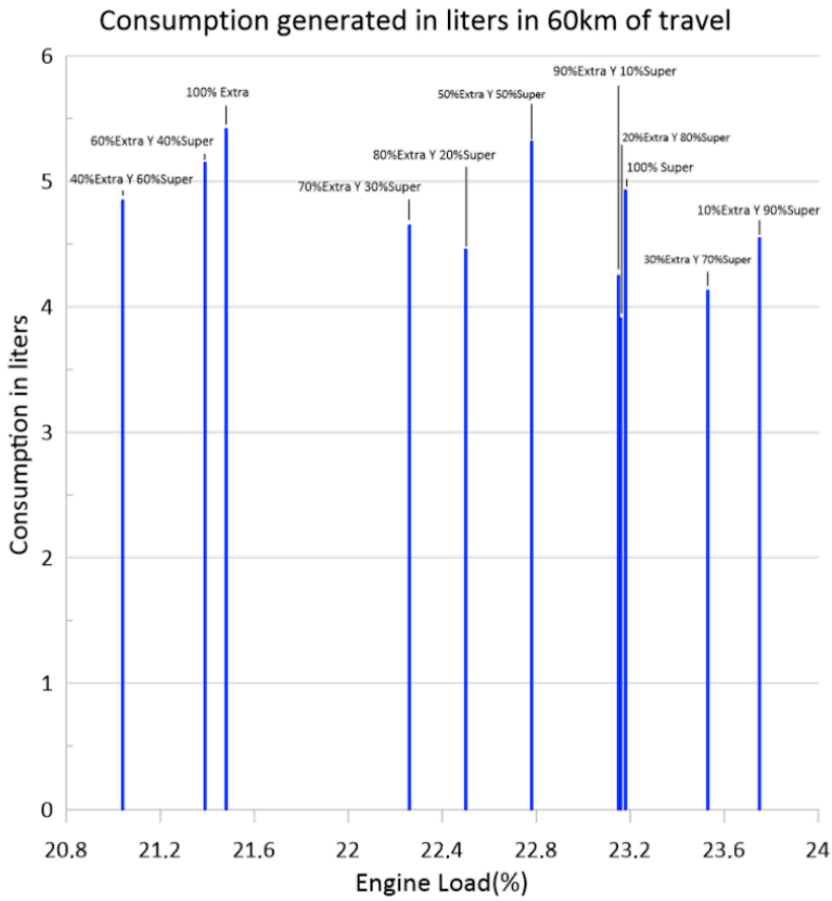

Figure 7. Gasoline consumption in 60 km of travel on Simon Bolivar Highway.

On the other hand, on the Simón Bolívar Highway, the following chronological order was indicated from higher to lower consumption: 100% extra, 50% extra and 50%, 60% extra and 40% super, 100% super, 40% extra and 60% super, 70% extra and 30% super, 10% extra and 90% super, 80% extra and 20% super, 90% extra and 10% super, 30% extra and 70% super, 20% extra and 80% super, and the load values varied between 2.71%.

Figure 8 shows the specific fuel consumption obtained between extra gasoline with E5 and E10 and super gasoline with E5 and E10 with respect to engine load, where it was observed that by increasing the percentage of ethanol with extra gasoline, there was less generated consumption and percentage of load due to the oxygenating agent that produces ethanol in the fuel, as shown in the studies carried out by Mohammed et al. [20]. On the other hand, super gasoline, having a higher-octane number, generated higher loads and fuel consumption by increasing the percentage of ethanol.

Figures 9 and 10 show the values of the CO_2 emissions generated in each mixture with respect to the load on Maldonado Avenue and on the Simón Bolívar Highway. All the values generated in each mixture varied significantly due to the amount of RON that was produced in each of the mixtures, as shown in studies carried out by Kumar [20], where it was specified that the mixture of alcohol with gasoline improved complete combustion and combustion efficiency. Additionally, alcohols increase the rate of combustion, leading to more constant volume combustion and complete combustion.

In Figure 11, it was observed that the mixtures of extra gasoline with E5 and E10 influenced the improvement in engine combustion, since in studies carried out by Mohammed et al. [20], it was shown that ethanol acts as an anti-knock agent in the combustion process and thanks to this, lower CO_2 emissions are generated. In contrast, in super gasoline, by increasing the percentage of ethanol, higher CO_2 emissions are generated and the engine requires a higher percentage of charge for its operation since, as mentioned in the studies carried out by Celik [37], increasing the octane of super gasoline tends to generate a higher calorific value, so more heat is accumulated and the engine requires a higher percentage of load for its operation.

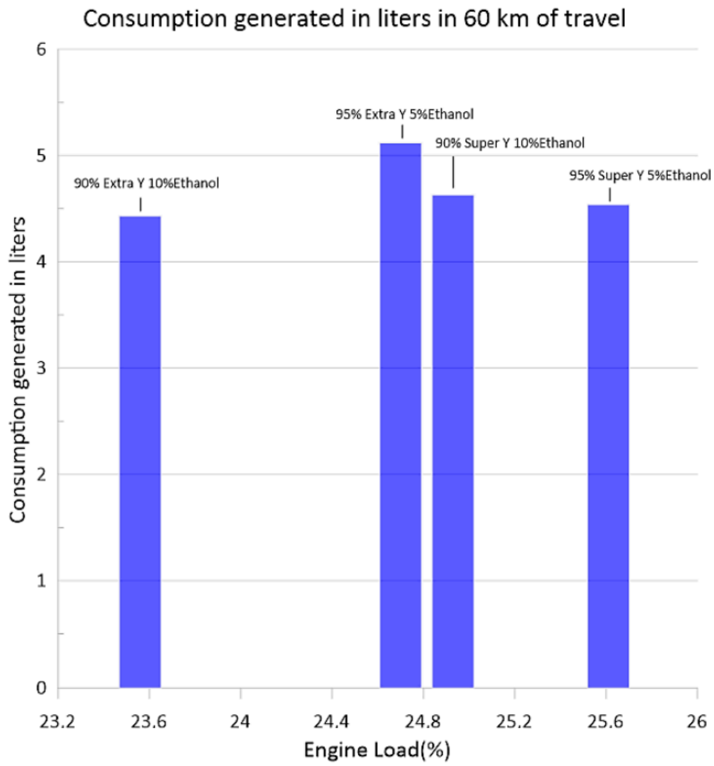

Figure 8. Gasoline/ethanol consumption in 60 km of travel on Simon Bolivar Highway.

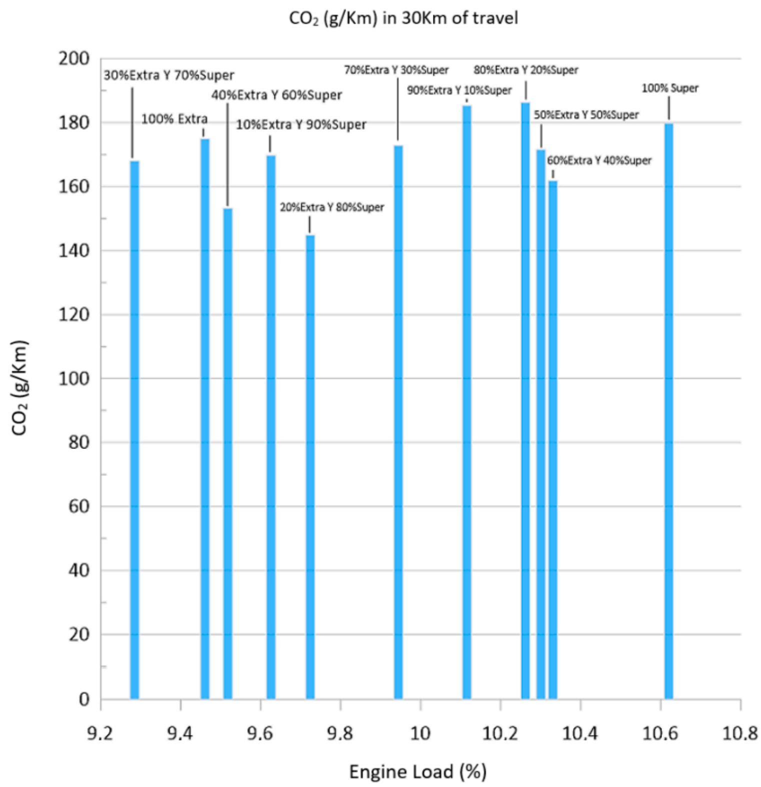

Figure 9. CO_2 (g/km) on Maldonado Avenue (30 km).

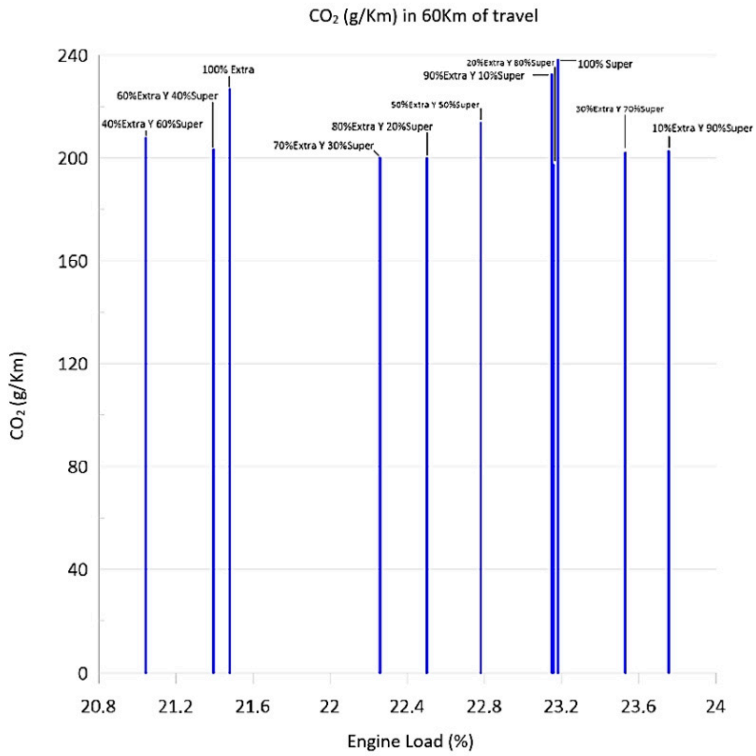

Figure 10. CO_2 on the Simon Bolivar Highway (all tests performed).

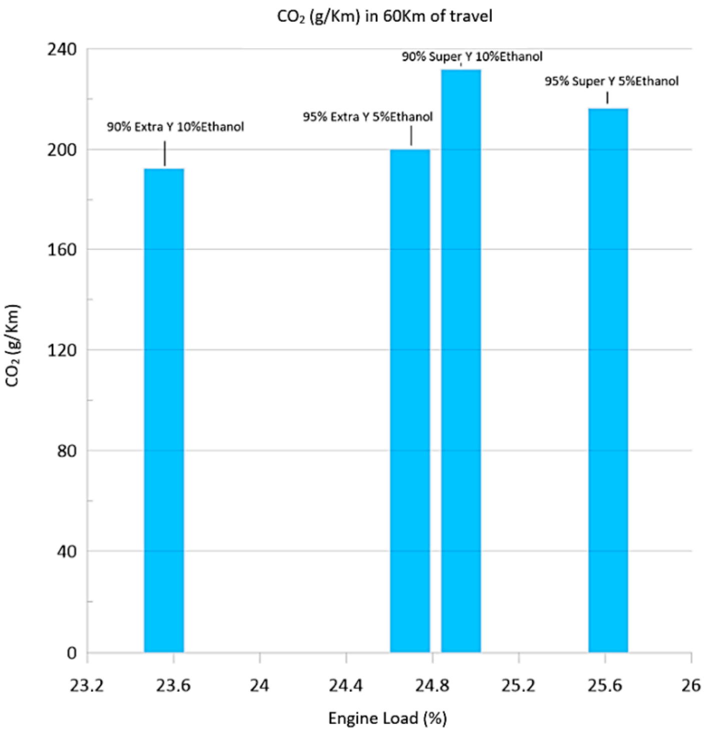

Figure 11. CO_2 on the Simon Bolivar Highway, more relevant tests, compared to pure fuel.

4. Discussion

The application of a driving cycle according to the regulations of the traffic law applied on Maldonado Avenue makes it possible for the experimental results to be more accurate, resulting in the mixture of 50% extra and 50% super being the most optimal at the level of economy and durability in relation to the consumption of kilometers per liter, at conditions of an average speed of 50 km/h, with a value of 5.32 L/km, thus maintaining a good operating condition in traffic situations and generating an efficient generated test result.

However, by applying the driving cycle based on traffic regulations on the Simón Bolívar Highway, with an average speed of 85 km/h, it allowed us to find a power reduced by 3% with the mixture of better economy (100% super), but maintained a similarity with the value of fuel consumption, with a percentage difference in consumption of less than 1%.

The most optimal mixtures with ethanol with the lowest quality fuel was with E10, which decreased the consumption but also the power of the performance based on the load of the engine, maintaining the lowest consumption and a more optimal operation development. This is because the amount of impure elements is very considerable, causing the stability of the mixture to be altered, so future studies should use phosphate-based stabilizers to keep the mixture of gasoline/ethanol more stable.

Similarly, the mixture of extra gasoline with E10 generated lower CO_2 emissions with a value of less than 15.13% compared to the mixtures with premium gasoline. Although the CO_2 data obtained in each mixture were variable, all values complied with the parameters established in the Ecuadorian Technical Standard INEN 2204 [38], and using the gasoline mixture 20% extra and 80% super on Maldonado Avenue and the Simón Bolívar Highway generated the minimum CO_2 emissions in the test.

In the present study, it was not possible to present a prediction model due to the number of tests and the variability of the data obtained in the fuel mixtures, so we recommend focusing on a single mixture test to analyze different conditions for the projection of fuel mixtures. It was determined that as the percentage of ethanol in gasoline increases, the engine tends to generate greater calorific value, so there is greater heat accumulation, and the engine has difficulties in its operation and ignition.

5. Conclusions

- The engine obtained the lowest fuel consumption on the routes traced with the mixture of 20% extra and 80% super, obtaining a value of 2.91 L, which when counteracted with the value of 100% extra, which consumed an average of 3.432 L on the routes drawn, decreased consumption by 15% on average. This indicates that making the mixtures to improve performance allows for similar consumption characteristics to be maintained, allowing a decrease in economic expenditure while maintaining the functionality of combustion.
- It was found that the ideal mix in the consumption and efficiency of engine development in torque generation was 70% super and 30% extra for engines with a compression ratio between 9:1 and 10:1, obtaining better performance and autonomy both on the road and in traffic circulation with 2.754 (9.08%) liters and 4.126 (16.3%) liters, respectively.
- It was determined that the most suitable fuel to generate blends with ethanol was extra gasoline, since it contains 86 octane and ethanol provides an oxygenating agent to reduce specific consumption and CO_2 emissions, respectively. This is because the premium gasoline, having more additives, generated an instability in the mixture, so a percentage higher than 5% causes a malfunction in the combustion.
- The mixture of extra with 10% ethanol (E10) reduced the CO_2 emissions and the vehicle had better performance and autonomy when compared to a value of 100% extra, showing a decrease in CO_2 of 15.13% in generation. This is the most optimal mixture dosing for both repair and fuel consumption.
- After the analysis, we deduced that the mixture of 5% and 10% ethanol, when mixed with super, had a low performance in the vehicle due to the increase in the number of RON in the mixture.
- It was found that on Simón Bolívar Highway, the mix between extra and super maintained the same consumption depending on the driving mode. This is because it is a road with stable average speed conditions, according to the existing traffic during peak hours.

- The ethanol mixture affects the vehicle due to its high vaporization content, which was analyzed as the content of stabilizers and additives to maintain the mixture is extremely relevant to keeping the stability of the blended gasoline. Ethanol showed a considerable improvement in fuel RON, in addition to considerably reducing the combustion emissions in the exhaust phase, improving fuel consumption in mainly traffic conditions and in stable road speed conditions.
- Due to the low compression ratio of the vehicle, it was not possible to mix gasoline with concentrations of E15 and E20, since the engine had ignition problems. In order to increase the amount of ethanol, engines with compression ratios greater than 10:1 must be used to avoid ignition problems, since ethanol decreases the calorific value of the mixture.

6. Recommendations

- It is recommended to make ethanol blends for direct injection vehicles with compression ratios greater than or equal to 10:1.
- Generate a database of the parameters obtained from the mixture of ethanol and gasoline to analyze volatility.
- Review the octane parameters of the ethanol and gasoline blends to verify the number of RON generated by each blend.

Author Contributions: Conceptualization, V.R.-R.; Methodology, J.A.-L.; Software, J.A.-L.; Formal analysis, H.Z.-B.; Investigation, V.R.-R., J.A.-L., H.Z.-B. and J.A.S.; Data curation, J.A.-L. and J.A.S.; Writing—original draft, H.Z.-B.; Writing—review & editing, V.R.-R. and J.A.S.; Supervision, V.R.-R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study did not require ethical approval.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: In memorial of the tragic death of our dear and appreciated student Ricardo Javier Guajala Agila of Universidad Politécnica Salesiana, Ecuador.

Conflicts of Interest: The authors declare no conflict of interest.

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