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Contents

ANALYSIS OF A CRASH ON A VEHICLE SYSTEM BY ADJUSTING APPROPRIATE INPUT PARAMETERS TO MANAGE ENERGY ABSORPTION CAPACITY FOR ENHANCING PASSENGER SAFETY

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Highlight
To develop a front bumper system that will absorb more energy than the present bumper in the case of a frontal impact.

Abstract
The aim of the research is to develop a front bumper system that absorbs maximum impact energy as compared to the current bumper available in the market, Bumper design is based on increasing the area of the crumping zone to slow down the collision and observe the impacts taking place at the time of jerks and reduces the percentage of damage. To develop the system, the number of load cases tested numerically in passive safety simulation has increased significantly in recent years. The variety of applications may be divided into three main topics: structural crashworthiness of the whole car, passenger protection, and crashworthiness of components. Present theories and practices. To absorb impact, the front bumper of the car uses a spring-loaded system that is installed between the bumper and the support for the chassis structure. This system is made of metal and serves as the bumper's structural foundation. A honeycomb structure is being added to the bumper as a composite material together with a layer of galvanized iron as it is being created in this manner, which increases strength while weighing less. This arrangement design is suitable for psychoacoustics, varying velocity explicit analysis is performed with the approach of finite element analysis, experimental testing is carried out for the validation of the value and advanced manufacturing methods are implemented with statistical results, and one of the cheapest systems is developed as compared to the current bumper systems.

Keywords
Bumper system, crash analysis, composite material, CAD, experimental testing, FEA.

Introduction

In an automobile, both the front and rear elements consist of a bumper system to resist the impact taking place on the vehicle and a system that absorbs shock to reduce damage (as in a collision). In the bumper system, a grill is implemented for ventilation purposes for a projected lamp for visibility, headlamps, and the aesthetic look of the vehicle. The aim of this paper is to highlight a system that is more suitable for modern automobiles with better passenger safety aspects. To develop this system, we have to consider various kinds of materials used, such as Galvin sheets, ABS plastic sheets, Honeycomb aluminium panels, etc., which are combined and put into one combination to make a composite material. This composite material is very strong, with high strength and less weight. The design has an aerodynamic effect. Research mainly focuses on parameters such as materials, design, CAD, GD&T, CAM, CAE-Simulation, Programming, Hand Calculation, Advanced Manufacturing Process, Experimental Testing, Validation, and Comparison Depending on all these criteria and parameters, the development of energy observing systems is done. It observes the energy inside it and reduces the impact, which is beneficial for the passenger for safety purposes. In automotive assiduity, energy immersion capability is veritably important in adding safety for passengers as vehicles are used considerably. Structural crashworthiness is an essential requirement in the design of the automotive corridor. Crashworthiness alludes to the reaction of a vehicle when it is engaged with or goes through an effect. Crashworthiness performance is good when there is less damage to the vehicle and passengers after a crash. Crashworthiness for structural members needs to be dissected before being enforced in the factual field [1]. This system is very helpful for the

development of an automobile. It has a unique component system that reduces the impact. Jerks and the percentage of damage to the passenger are very low, and they are also in a safe zone with a safety factor, and the manufacturing cost is very low in comparison to others. Figure 1 highlights the basic representation of the energy-absorbing bumper system.

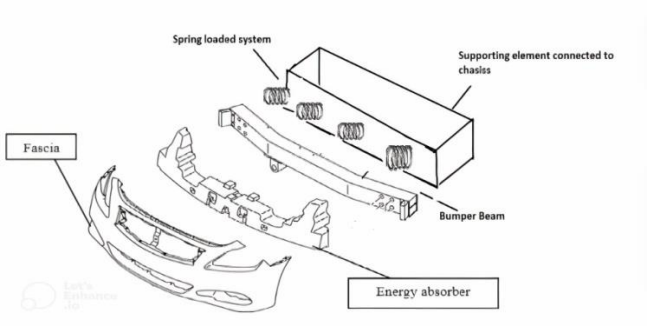


Figure 1. Automobile Front Bumper (Energy Absorption System). *Source: Own.*

Methods

Research studies

Objective is to study bumper system and design and development a bumper system which absorb maximum energy inside bumper system in the form of a crumping zone and more effective as comparing to the present bumper, According to the aforementioned literature research, an appropriate impact force distribution can enhance a bumper's performance in terms of a vehicle's and its occupants' safety. Additionally, there are methods for efficiently dispersing the energy that the bumper system absorbs in order to achieve safety with the least amount of damage. An investigation was conducted [2]. Found that balancing the weight of bumper system components by controlling their thickness may lead to lower stress levels, which indirectly protects the safety of the components. Since the energy from impacts is distributed equally among the components and we may fortify the components during assembly thanks to the properties of the material, the use of varied materials is justified. Also. For fenders that might devaluate further energy, design specifications must be determined. According to the experimental disquisition report and study trouble applicable to advancements in the frontal cushion design of a passenger auto, there are some significant factors that may be taken into consideration for enhancement and a gap in the literature.

- The bumper's ability to absorb energy must be increased considering the friction damper.
- A novel energy perception framework is required, which can notice the energy inside it and decrease the effect, like a spring-stacked framework or hydraulic cylinder.
- Experimental data for analysis of passenger safety.

Material Properties & Analysis

The bumper system consists of two major component system one is the spring-loaded system which is connected inside the bumper to the chassis other is the body parts of the bumper system as shown in the Figure 2 both analyses is carried out for the selection of the better material, Proper alloy composition is made which contains different percentages of material properties. Also, proper solidification time is given to extract material properties at the time of manufacturing so it can sustain maximum impact on the materials.

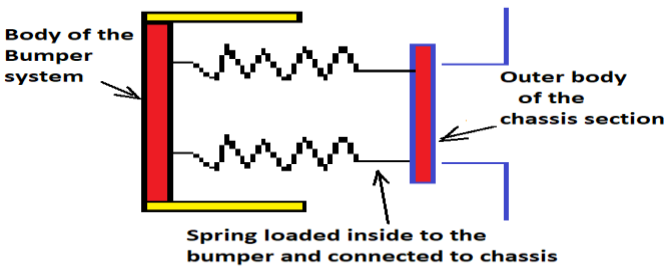


Figure 2. Different component systems used for the bumper. *Source: Own.*

Diverse types of materials are used to build bumper systems and composite materials are also utilized, aver materials have different properties; with varied materials taken into consideration for the system's study, the goal is to analyse each of these materials in terms of low weight and high strength. The typical characteristics of the Guard are listed below, mainly consisting of the Chief Tomahawks of Dormancy and the Head Snapshots of Inactivity, etc. The mechanical characteristics of the guard plan framework for energy retention are displayed in Table 1 below.

Table 1. Material Properties for the bumper system. *Source: Own.*

Material	**Modulus of elasticity E (GPa)**	**Poisson's ratio μ**	**Yield strength S_y (MPa)**	**Density ρ (kg/m³)**
AISI 316 Stainless Steel Sheet (SS)	211	0.265	170	8027
Aluminium 1345 Alloy	59	0.33	28	2700
S2 Glass	86.9	0.23	310	2460
ABS Plastic	2.5	0.394	48	1050

In the Solid Works tool mass properties analysis is done for the bumper system as shown in Table 2

Table 2. Mechanical Properties for the Bumper Design Systems. *Source: Own.*

Mass	**Volume**	**Surface area**	**Centre of mass: (inches)**
6202.89 grams	6202890.90 m^3	3616.72 3 in^2	X = -51.35 Y = -1.14 Z = -17.39

A bumper design configuration and coordinate system are defined as shown in the Figure 3, the system diagram is obtained in CAD tool and analysed parameters.

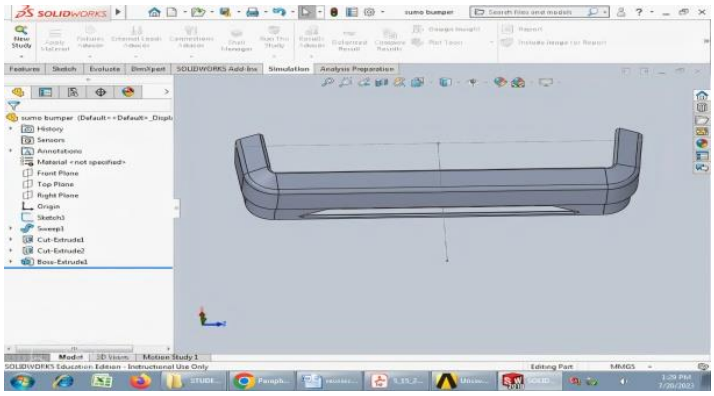


Figure 3. Bumper system configuration diagram. *Source: Own.*

Following material analysis is carried AISI 316 Stainless Steel Sheet (SS), Aluminium, Glass and ABS plastic, for checking suitable material as shown in Table 3

Table 3. Materials analysis for selecting suitable material and model outcomes for auto front guards. *Source: Own.*

Parameters	**ABS Plastic**	**S2 Glass**	**AISI 316 Stainless Steel Sheet (SS)**	**Aluminium 1345 Alloy**
Absolute Disfigurement	0.31992	0.26661	0.74322	1.23211
Stress	1.40e+09	1.17e+10	879083.88	877002.44
Strain	1.5741	0.15533	0.000002	0.000001

Consisting of material properties and bumper analysis we can predict S2 Glass fibre is a better material, Also implement steel sheet combined with polycarbonate which act as a honeycomb structure reinforcement as

compared to the analysis point of view is stronger and light weight, Outright Deformation 0.2155, stress 1.05e+10 N/m². Different part is made of different material in the bumper which act as the composite material.

The chemical properties of chromium-vanadium steel springs as shown in Table 4 are considered for the development of spring-loaded bumper system, a spring is a very critical element in this system. The chemical composition is very important at the time of the manufacturer's spring. If some percentage mismatch takes place, the breakdown of the spring occurs after a few intervals of time. Table 4 refers to the chemical properties for developing the energy absorption material [3,4].

Table 4. Chemical compositions considered for developing energy absorb system. *Source: Own.*

Carbon	**Silicon**	**Vanadium concentrations**	**Magnesium**	**Chromium (Cr)**	**SAE Steel Grade**
0.4% to 0.5%	(0.3 to 0.5% Si)	0.1 to 0.2%.	0.5 to 0.8% Mm	0.9 to 1.1%	6000 Series

Deformation takes place when a load is applied to the spring in the energy absorbed, the spring will be returned to its original state by means of the oscillating motion when you quickly launch a weight from this position. With this technique, the spring builds strength through deflection when the load is applied [5,6]. When there is a crash, the energy is absorbed and transformed into a system's internal potential energy, the spring-loaded bumper system has 11493397.4 psi as material shear modulus**.**

Energy absorption impacts fundamental and the bumper system's-built structure.
The equation below shows the impact analysis fundamentals that are used to solve impact elastic and plastic & available in two different varieties. Energy and momentum conservation equations can be expressed as follows.

(1) $$\frac{1}{2}\mathfrak{m}_{A}\mathcal{V}_{\mathrm{A}}^{2}=\frac{1}{2}\mathfrak{m}_{A}\mathcal{V}_{\mathrm{A2}}^{2}+\frac{1}{2}\mathfrak{m}_{B}\mathcal{V}_{\mathrm{B2}}^{2}$$

(2) $$\mathfrak{m}_{A}\mathcal{V}_{\mathrm{A}}=(\mathfrak{m}_{A}+\mathrm{m}_{\mathrm{B}})\,\mathcal{V}_{0}$$

Where $\mathfrak{m}_{A}$is the mass of the impactor$\mathfrak{m}_{B}$the mass of the vehicle, $\mathcal{V}_{\mathcal{A}}$ the haste of the impactor before impact, and $\mathcal{V}_{0}$ the final haste of the impactor and vehicle at the moment of highest deviation point.

The coefficient of restitution (e) can be used to calculate the velocities following a collision.

(3) $$\frac{\mathcal{V}_{\mathrm{B2}}-\mathcal{V}_{\mathrm{A2}}}{\mathcal{V}_{\mathrm{A}}-\mathcal{V}_{\mathrm{B}}}$$

The impactor's kinetic energy prior to the impact

(4) $$E\mathrm{plastic}=\frac{1}{2}\mathfrak{m}_{A}\mathcal{V}_{\mathrm{A}}+\frac{1}{2}\mathfrak{m}_{B}\mathcal{V}_{\mathrm{B}}-\frac{1}{2}\mathfrak{m}_{A2}\mathcal{V}_{\mathrm{A2}}-\frac{1}{2}\mathfrak{m}_{B2}\mathcal{V}_{\mathrm{B2}}$$

The chassis serves as a supporting element for the bumper system; it is made of lighter carbon steel or aluminium alloy. At the rear and front end of the chassis, a bumper system is implemented on a horizontal beam in this same beam with a perpendicular formation. We have added a series of spring-loaded systems to observe the energy. A spring-stacked system is planned in such a manner to utilize a twist spring to store energy from contorting movement. It additionally notices the strain inside and delivers the energy the other way. Spring-loaded systems observe maximum energy inside them, and very little energy is transferred to the passengers. At the time of impact, the forced distribution takes place in a circular motion to reduce the impact. Also, we can implement a hydraulic cylinder inside the chassis at the vertical front of the chassis body. This is one type of suitable method that can be implemented in vehicles and is a very cost-effective method where the vehicle falls under a safety zone. This method can be used to make a vehicle five-star under the Global NCAP rating and is a more suitable method. Also, we can implement a crash box that can be fitted between the chassis and the bumper element. This type of method is adopted nowadays in vehicles. As compared to our system, a hydraulic cylinder for the vertical component has been installed at the front of the chassis. The horizontal front beam of the chassis part has a spring-loaded mechanism added to it to cushion the blow. This system is fitted between the vehicle

chassis and the inner element of the bumper. A series of springs are added in this system at the front frame of the chassis section. The formation of a collusion force takes place. Spring sustains the impact and bumper life is increased. This system is very suited for the off-roading area in its rigid condition, and for high to low ground clearance, it is very effective. Chrome strips were added for support and styling purposes and to enhance the look. This system is fitted between the front chassis section and the inner element of the front bumper. Further, the outer body of the bumper is made with a honeycomb structure in a natural hexagonal honeycomb formation. The structures are used to build the bumper system, which consists of a PVDF coating with rigidity and stability for the panel. They are fixed inside and outside of the bumper system with an inside honeycomb structure between them. They are also used for aerospace applications, known as ACP aluminium panel sheets. In this panel, we are using the pattern of an, I beam, which has the most strength with less weight, which enhances its efficacy to withstand extreme stress. They also act as heat and sound insulation, which reduces engine noise. The hexagonal structure of the sheets has a hollow space in the middle that inhibits airflow and prevents heat and sound from passing between the sheets. Once the honeycomb structure was completed according to the parameters, we added a Galvin sheet that acts as a composite material; galvanized metallic systems are widely used for exterior buildings in the current metropolitan society, including crash barriers, lamp poles, fences, buildings, facades, and roofs. A heat treatment process is used to increase its strength. An electroplating process has been applied to metal surfaces using warm dipping [7,8]. The first layer will be aluminium-coated, and the second layer will be I beam of honeycomb. The third layer will be aluminium, and the fourth layer will be a Galvin sheet. The combination is in such a way that it has high strength with less weight so that maximum strength will increase. In an automobile, both the front and rear elements consist of a bumper system to resist the impact taking place on the vehicle and a system to absorb shock to reduce damage (as in a collision). In the bumper system, a grill is implemented for ventilation purposes a projector lamp for visibility, and headlamps. The aesthetic look of the vehicle becomes good. It is the most advanced concept that can be implemented in an automobile front bumper system for passenger safety aspects. Low manufacturing costs with rapid advanced production [9]. Figure 4 highlights the bumper system different components and the built structure of it.

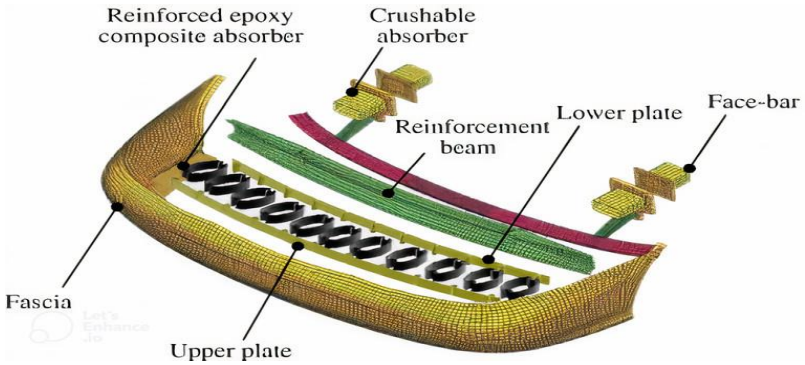


Figure 4. Bumper System with exploited View. *Source: Own.*

Results and discussion

Bumper system simulation

The most important thing to consider in the development of automobile front bumper systems is that we have defined the physical parameters such as thickness, length, height, different angles, angle of curvature, internal Di & external Do diameter, Ti-difference between two elements, Th-thickness of the supporting element, Ao-the difference between slot area and aesthetics look is created for the beauty of a bumper system. After designing, we implement the Pre-Processing, Processing, and Post-Processing Phases. We also implement Mat-Lab platform Programming supporting Simulation and Calculation.

Base model evaluation

We are provided a cushion assembly, as shown in Figure 5, whose component consistency is specified in the table.

The automobile's front bumper panel consists of various parts. The thickness for the base model ranges between 1.50 mm and 12 mm, and the chassis section is 10 mm. The analysis is divided into three parts: pre-processor, processor, and post-processor. Pre-Possessor – The process mainly consists of discretization into a number

of small parts, each part consisting of a node and an element they are properly connected to one another, allowing force to transfer from one side to the other and acquire static or dynamic loading conditions [10]. Mostly, this process is followed to convert an infinite into a finite for a higher thickness component; we use a top-down approach where the mesh is created on the top face and extended to the bottom face. For the smallest thickness at midplane, the mesh is created by extruding on both faces. Since the third feature of a multitude of variables, consistency is negligible compared to the other two constraints, length, and range, we prefer 2D meshes or hulls. Furthermore, the conjunction provisions do not impose permanent limitations on the effective section. After recording, the model looks like Figure 6. The type of network, a fitted model, is also examined. Once the mesh is created, the model is assessed for quality and compliance to standards, allowing precise characterization of stress zones and mapping surrounding boundaries across material packages, similar to the modulus of plainness and venom rate [11,12].

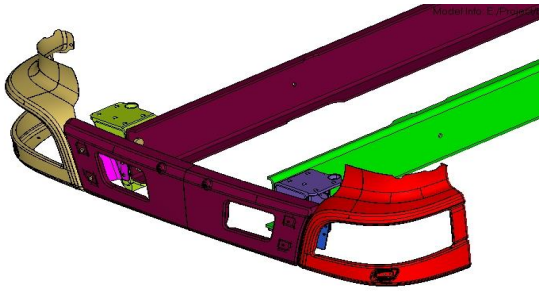


Figure 5. Assembly of the Bumper System of the Base Model Analysed. *Source: Own.*

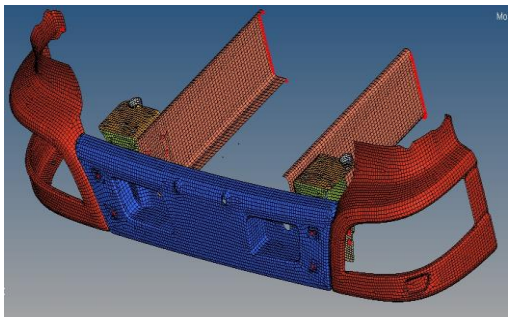


Figure 6. Bumper system assembly mesh model (front view). *Source: Own.*

The viscosity of the material, etc. we are handed a sword as an introductory material, whose parcels are described in Table 5 below.

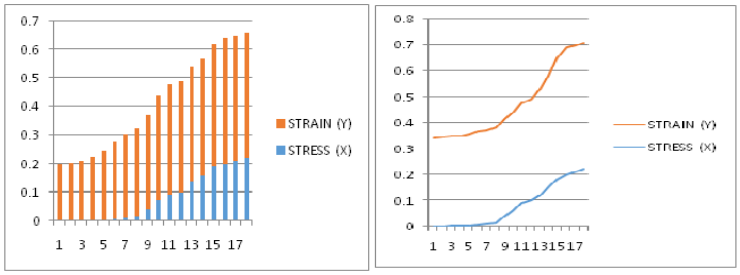
Table 5. Steel Material Characteristics. *Source: Own.*

Material	**The elasticity modulus**	**Density**	**Poisson ratio**
Steel	215 kN/ mm^2	7.9e^-6 kg/ mm^2	0.3

Soft steel is used to make the front panel and side panel of the car's front bumper, whereas the chassis portion and support bracket are composed of tough steel, and the impactor is stiff. In addition, this material is divided into two groups: mild steel and durable steel, which are allocated to components like these. Below are the values and angles of the stress vs. strain charts for the two materials. Figure7 highlights Stress-Strain for the soft & hard steel [13].

Soft & durable steel compression between Stress-Strain is highlight in Figure 8, the non-linear curve used to compare durable steel to soft steel; Boundary conditions refer to issues that arise during analysis. This has to do with fixing the model, operating the loads, providing the right connections, etc.

Following that, we are given the restricted circumstances, the vehicle's mass, which is approximately 1000 kg, and the impact speed, which is 1.5 m/sec. Shafts provide bolt couplings, which are thus properly constrained. The processing stage is where FEA equations are used to solve the stages and compile the findings of the study.



Stress-strain curve data for soft steel **Stress-Strain curve data for hard steel**

Figure 7. Data on the stress-strain axes for both soft and durable steel. *Source: Own.*

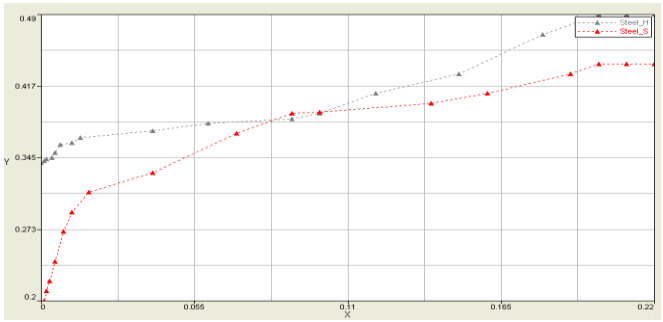


Figure 8. Comparison graph between hard and soft steel. *Source: Own.*

Post-Processor (Base Model)

The Results of the analysis are displayed in the hyperview module after completion and validated with the corresponding method. Figure 9 and Sub Figure 9 A-B-C-D-E; highlight the Base model analysis for different components.

For soft swords, the acceptable values for plastic deformation are 0.25 (25) and 0.33 (0.33), respectively. The support type (cushion type) is 0.33, which is higher than the allowed value. Because of this, the bumper side panel's design is dangerous, and the real amount of plastic deformation must be lowered to a reasonable level. The plastic strain value for the first swelling model is shown in Table 6.

For components made of soft steel, the allowed values for plastic strain are 0.25 (25%) and 0.33 (33%) for those made of durable steel. We conclude that the bumper bracket exceeds the actual allowable strain value, as indicated in Table 2. Making the appropriate tweaks to the assembly process will help to secure the design by bringing the plastic strain values down to a manageable level. To make sure that all components enter the safe zone, a modified analysis of the basic model is carried out based on the findings. Therefore, the accompanying Table 4 [14,15], provides the fundamental model with the change in element thickness.

Table 6. Displays the plastic strain values for each part of the original model in the complex model. *Source: Own.*

The name of the component	The model's original thickness	Model original Plastic strain
Body of the bumper's front panel	1.7 mm	0.26 (26%)
Panel on the bumper's side	1.7 mm	0.08 (8%)
Part of the bumper panel that supports the brackets	4.0 mm	0.35 (35%)
Component of the supporting bracket	11.0 mm	0.21 (21%)
Body section	10.0 mm	0.01(1%)

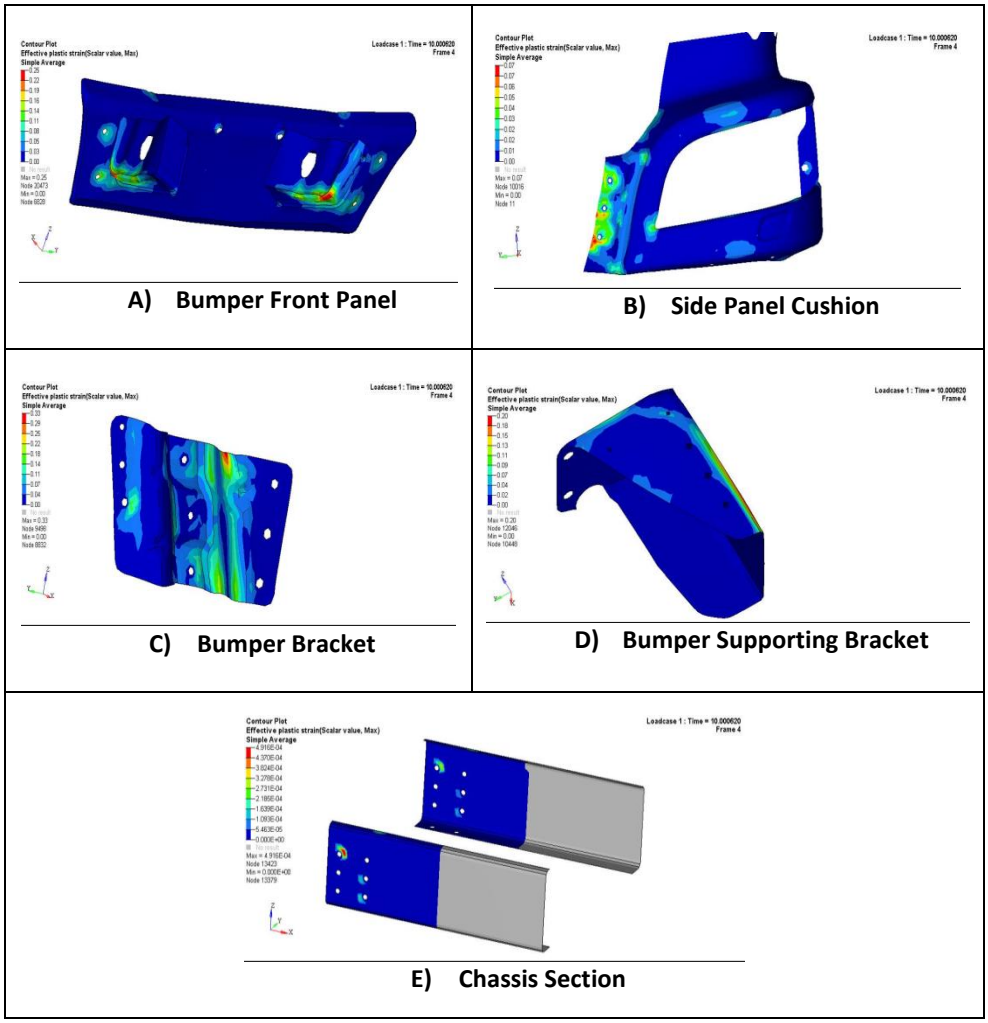


Figure 9. Contour diagram analysis of the actual values of plastic deformations of various parts of the front bumper and chassis sections. *Source: Own.*

Possible solutions are:

- Redesigning components: To get the best results we can redesign the component. This results in the redesign of components, increasing costs by adding more ribs or changing calculations.
- Material modifications: Component materials can be modified to ensure appropriate pressure distribution. We can use additional composite materials to avoid poor design.
- The thickness of each component can be varied to determine the correct plastic strain values for each component. The promotion process is expensive and time-consuming. To determine plastic strain values and create a safe strategy, we choose the third option from the list above.

Changed Guard front board and skeleton area examination.

As a result, the new front bumper panel of the car had a thickness ranging from 2 to 12 mm and the chassis section had a thickness of 10 mm. This led to the creation of the upgraded model with the modified component thickness for the new bumper assembly. With the same limit circumstances after the thickness adjustments, the effects of the modified model are as follows: Figure 10 and sub-Figure 10 A-B-C-D-E display the component analysis of the improved bumper system for various sections.

For the vehicle chassis and front bumper parts, the plastic deformation values are between 0.26 and 0.01, which is equal to or lower than the permissible limit. This makes the structure safe. If it is in a safe zone, we can take the changed value into account and run the project. Table 7 shows the modified plastic deformation of the model.

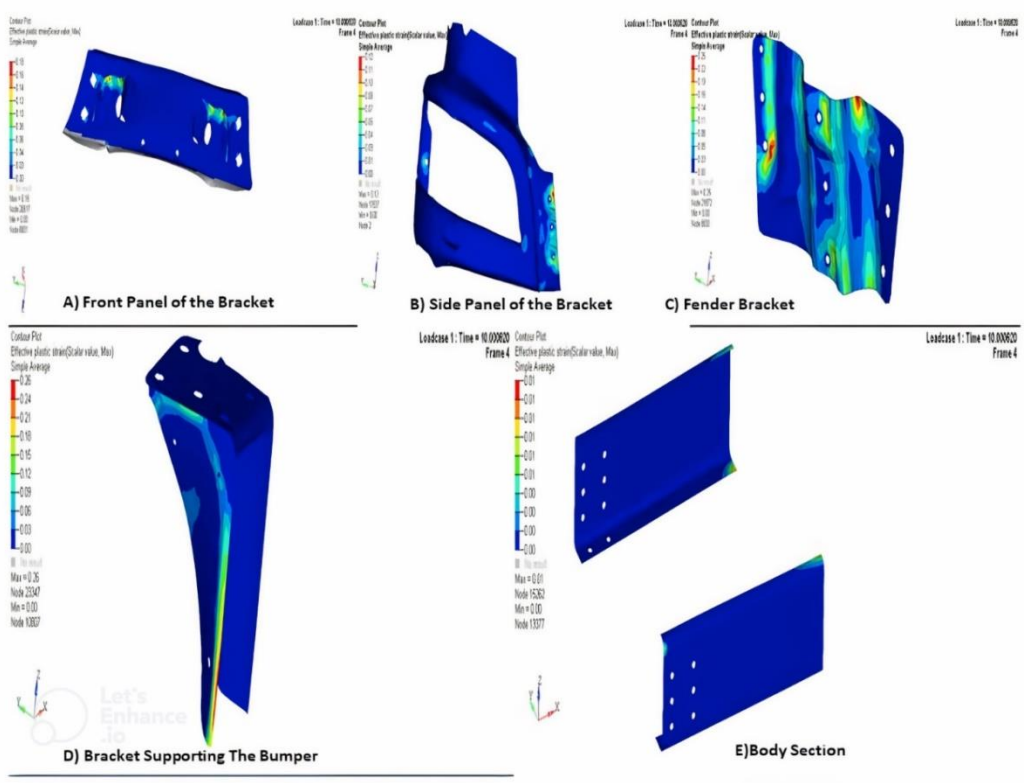


Figure 10. Contour plot study of actual plastic strain values for chassis section and front bumper panel modifications. *Source: Own.*

Table 7. Values for Plastic Strain in Changed Guard Get-together. *Source: Own.*

Name of the part	The thickness of the model has changed	Altered model
Panel in front	2.0 mm	0.18 (18%)
Lateral panel	1.6 mm	0.12 (12%)
Bracket	6.0 mm	0.25 (25%)
Supporting Bracket	11.0 mm	0.26 (26%)
Chassis	10.0 mm	0.0004 (0.04%)

For mild steel, the permissible plastic deformation values are 0.25 (25%) and for durable steel 0.33 (33%). Table 8 shows the compression between the original and modified models.

Table 8. Compare the results of the original and revised models. *Source: Own.*

Name of the part	Model's original thicknesses	The values of the initial model strain	Model thicknesses have been modified	Values for model strain have been changed.
Panel in front	1.7 mm	0.26 (26%)	2.00 mm	0.18 (18%)
Lateral panel	1.7 mm	0.08 (8%)	1.60 mm	0.12 (12%)
Bracket	4.00 mm	0.35 (35%)	6.00 mm	0.25 (25%)
Supporting Bracket	11.00 mm	0.21 (21%)	11.00 mm	0.26 (26%)
Chassis	10.00 mm	0.01 (1%)	10.00 mm	0.0004 (0.04%)

The allowable plastic strain grades are 0.25 (25%) and 0.33 (33%) for components manufactured of strong steel and sensitive steel, respectively. All the components in Table 4's updated model piece are therefore within a reasonable distance [2,16]. To approve it, we have also defined the real boundary; we have computed each component design calculation using the traditional way of analysis (by hand), Explicit analysis in LS-DYNA R11.2.0

has been carried out for varying velocity as shown in Table 9; S2-Glass fibre combined with aluminium sheet is used as composite reinforcement material in the analysis as per analysis deformation is increases with increases the velocity comes in the contact of collision also Bumper design has perform under asymmetric loading and it is suitable for asymmetric loading condition.

Table 9. Explicit analysis result carried in LS-DYNA. *Source: Own.*

Part	Material	Speed Km/hr.	$v$final (m/s)	Body Mass(kg)	Collision Distances d(M)	KE (J)	F (N)
Bumper System	Composite	52 to 57	14.7222	1200	0.100	129654	1296540
	Composite	58 to 62	16.3889	1200	0.110	159414	1449218
	Composite	63 to 68	17.7778	1200	0.150	375948	2506320

Experimental Testing

The experimental testing method was adopted according to the standards of AIS-006, the test procedure is designed to violently impact a raised piston, vertically connected at the top centre, against the bumper system and use the impact to calculate the degree of destruction and rupture of the material. The results show that the material fracture on the vehicle occurs under the influence of the crack propagation generator at the time of impact of the settlement mechanism and considering the material damage. The Experimental set-up as shown in Figure 11 below is designed to test the vehicle bumper during impact conditions, ram angle is used at impact to test the sidewalls and calculate the impact of the anti-slip bumper system. The structure of the building is very simple and in a classic style [17,18].

Furthermore, we have shown the parameters and mathematical formation with expression. Impact testing is carried out to determine how much energy is absorbed or how much energy is required to destroy the unit under test (UUT). Engineers can reduce the impact force of a car by increasing the stopping distance by using "crumple zones," where the distance travelled matches the change in kinetic energy, according to the work-energy principle, where the average impact force times the design., F = ma [N] to calculate the anticipated impact force. Using the final haste calculated from the discussion of energy Equation v = √ 2gh, [m/s)] we may cipher the performing impact acceleration.

The network performed during an impact is equal to the average impact force times the impact's travel distance.

(5) $$\text{Wnet} = {}^{1}/_{2}\, m_{final^2} - {}^{1}/_{2}\, m_{initial^2}$$

In a drop test operation a drop,

(6) $$\text{Wnet} = {}^{1}/_{2}\, m_{final^2}$$

Since the original haste ($\mathcal{V}$initial) is equal to zero. Assuming one could fluently estimate the impact distance, the average force, F, is calculated as follows.

(7) $$F = \frac{\text{Wnet}}{\text{d}}$$

where d = distance travelled [mm]

Results of the experiment: This was done to verify the impact performance of the various vehicle bumper system components using the Impact Pendulum Test Method. Values are displayed with a safety factor for modified bumper systems that meet the safe standards. We tried them with various strategies to approve them. The experimental results are highlighted in Table 10.

Figure 11. Experiment Setup with Specimen. *Source: Own.*

Table 10. Experimental testing Data. *Source: Own.*

Part / component name	Modified model thickness	Modified model Plastic strain values
Front panel	2.00 mm	0.21
Side panel	1.6 mm	0.14
Bracket	6.00 mm	0.20
Supporting Bracket	12.00 mm	0.18
Chassis	10 mm	0.02

A low-speed crash test was performed for experimental testing of the bumper system the parameters were set as 3km/h for the side and 5 km/h for the front panel testing, the vehicle hit with this speed to the rigid barrier and checked for the deformation, Table 11 below shows experimental testing results from a low speed.

Table 11. Velocity version experimental testing of the bumper system. *Source: Own.*

Mass of the vehicle	Impact parameters	Impact Velocity	Average Impact Force (kN)	Peak Impact Force (kN)	Kinetic Energy (kJ)
1000 Kg	Front Panel	8 km/h	24.691	49.383	2.4691
	Side panel	4 Km/h	6.173	12.346	617.2840

As per experimental testing result analysis, we can predict bumper design is under safe zone, design is succeeding in achieving crumple zone to absorb impact energy during a collision.

Comparison & Validation

The current market SUV standard model is compared with our base model of SUV. As per comparison, the standard method is followed. Further, we have validated the design as per ISO standards with a satisfying outcome. This framework is according to the direction of information and determinations of ARAI. The platform was designed and modified to support NCAP Global' s standing. The platform is designed to withstand crashes and is suitable for all materials and amalgamations. We have also validated all the parameters such as Design CAD GD&T, CAM & Analysis, Testing, Simulation, and Programming with real-time performance data. Taking all these factors into account, we can conclude that the development of a machine front cushion system that observes energy and sustains impact at the time of the crash and keeps the passenger within the safety zone with a low-cost, high-performance outcome with continuity. Table 12 shows the comparison of experimental, analytical, and experimental testing reports [19,20].

As a result, it was discovered that the trial tests agreed with the analytical values suggested. Consequently, the bumper assembly's design is secure.

Table 12. Correlation of exploratory and examination results for the base model and changed Calculation. *Source: Own.*

Name of the component	Strain values (existing geometry) by analysis	Strain values (novel base geometry) by experimentation	% difference
Front panel	0.18 (18%)	0.21	+3
Side panel	0.12 (12%)	0.14	+2
Bracket	0.25 (25%)	0.20	-5
Supporting bracket	0.26 (26%)	0.18	-8
Chassis	0.0004 (0.04%)	0.02	+1.9

Impact

The bumper system analysis results can be developed to absorb maximum impact energy and enhance passenger safety. The use of composite materials and advanced manufacturing processes further contribute to the strength and durability of the bumper system. As technology continues to advance, it is important to continuously improve and innovate bumper systems to ensure the safety of vehicle occupants, When comparing the modified bumper system with the current market standard models, the performance and safety of the modified system are found to be superior, experimental testing is conducted using impact pendulum testing to verify the impact performance of the bumper system components. The results of the testing show that the modified bumper system meets the safe standards and effectively absorbs energy during a collision. Low-speed crash tests are also performed, and the results demonstrate that the bumper design is within the safe zone and successfully achieves crumple zones to absorb impact energy, this system can be implemented in automobile for better safety with cost effective.

Conclusions

A unique system has been developed to reduce the cost with a higher outcome. Cost-effective method that is 30% less expensive than the regular method Furthermore, we can implement this system in automobiles. Different material analyses were done & and investigated the suitable material for automobile bumper systems that absorb max impact energy with less weight strength, Several sensitivity analyses were conducted on a design that is better than the regular design. It observes the maximum impact and endures under it. In terms of energy absorption, it resists 50%, and the percentage of damage to passengers is reduced. Also, the design is aesthetic and eye-catching. By comparing standard models with modified and new innovation-generated versions of the models, we can predict the above results. This system can be preferred for hatchback sedans and SUVs to achieve a better Global N-Cap rating.

Conflict of interest

There is no conflict of interest.

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References

[1] N.S. Muhammad, A. Hambali, J. Rosidah, W.S. Widodo, M.N. Ahmad, A review of energy absorption of automotive bumper beam, Int. J. Appl. Eng. Res. 12 (2017) 238–245.

[2] J. Marzbanrad, M. Alijanpour, M.S. Kiasat, Design and analysis of an automotive bumper beam in low-speed frontal crashes, Thin-Walled Struct. 47 (2009) 902–911. https://doi.org/10.1016/j.tws.2009.02.007.

[3] L. Mei, C.A. Thole, Data analysis for parallel car-crash simulation results and model optimization, Simul. Model. Pract. Theory. 16 (2008) 329–337. https://doi.org/10.1016/j.simpat.2007.11.018.

[4] A. Bhuyan, O. Ganilova, Crush can behaviour as an energy absorber in a frontal impact, in: J. Phys. Conf. Ser., 2012: p. 012009. https://doi.org/10.1088/1742-6596/382/1/012009.

[5] R.E. Elewa, S.A. Afolalu, O.S.I. Fayomi, Overview Production Process and Properties of Galvanized Roofing Sheets, in: J. Phys. Conf. Ser., 2019: p. 022069. https://doi.org/10.1088/1742-6596/1378/2/022069.

[6] N. Abedrabbo, R. Mayer, A. Thompson, C. Salisbury, M. Worswick, I. van Riemsdijk, Crash response of

advanced high-strength steel tubes: Experiment and model, Int. J. Impact Eng. 36 (2009) 1044–1057. https://doi.org/10.1016/j.ijimpeng.2009.02.006.

[7] X. Yang, Y. Xia, Q. Zhou, P.C. Wang, K. Wang, Modeling of high strength steel joints bonded with toughened adhesive for vehicle crash simulations, Int. J. Adhes. Adhes. 39 (2012) 21–32. https://doi.org/10.1016/j.ijadhadh.2012.06.007.

[8] R. Gümrük, S. Karadeniz, The influences of the residual forming data on the quasi-static axial crash response of a top-hat section, Int. J. Mech. Sci. 51 (2009) 350–362. https://doi.org/10.1016/j.ijmecsci.2009.03.010.

[9] C.L.F. Rocha, D.A.K. Fabricio, V.M. Costa, A. Reguly, Quality assurance of absorbed energy in Charpy impact test, in: J. Phys. Conf. Ser., 2016: p. 012009. https://doi.org/10.1088/1742-6596/733/1/012009.

[10] E. Wilhelm, L. Rodgers, R. Bornatico, Real-time electric vehicle mass identification, World Electr. Veh. J. 6 (2013) 141–146. https://doi.org/10.3390/wevj6010141.

[11] Y.Q. Sun, C. Cole, M. McClanachan, The calculation of wheel impact force due to the interaction between vehicle and a turnout, in: Proc. Inst. Mech. Eng. Part F J. Rail Rapid Transit, 2010: pp. 391–403. https://doi.org/10.1243/09544097JRRT350.

[12] T.L. Teng, F.A. Chang, Y.S. Liu, C.P. Peng, Analysis of dynamic response of vehicle occupant in frontal crash using multibody dynamics method, Math. Comput. Model. 48 (2008) 1724–1736. https://doi.org/10.1016/j.mcm.2007.10.020.

[13] M. Of, R. Transport, Automotive Vehicles - External Projections -Performance Requirements for M1 Vehicles, Automot. Res. Assoc. India. (2016) 1–18.

[14] ECE, Uniform Provisions Concerning the Approval of Vehicles With Regard To Their Front and Rear Protective Devices (Bumpers, Etc.), 1980.

[15] F. Xu, X. Tian, G. Li, Experimental Study on Crashworthiness of Functionally Graded Thickness Thin-Walled Tubular Structures, Exp. Mech. 55 (2015) 1339–1352. https://doi.org/10.1007/s11340-015-9994-3.

[16] PCB Piezotronics Incorporation, Impact and Drop Testing, New York. (2007) 1–14.

[17] D. Johnsen, L. Ostendorf, M. Bechberger, D. Strommenger, Review on Smart Charging of Electric Vehicles via Market-Based Incentives, Grid-Friendly and Grid-Compatible Measures, World Electr. Veh. J. 14 (2023) 25. https://doi.org/10.3390/wevj14010025.

[18] H. Chang, Z. Su, S. Lu, G. Zhang, Application of Deep Learning Network in Bumper Warpage Quality Improvement, Processes. 10 (2022) 1006. https://doi.org/10.3390/pr10051006.

[19] K. Kumar, Journal of Automobile Engineering and Applications Study of Two-distinct Automotive Bumper Beam Designs during Low speed impacts, J. Automob. Eng. Appl. 7 (2020) 16–28. www.stmjournals.com.

[20] A.T. Beyene, E.G. Koricho, G. Belingardi, B. Martorana, Design and manufacturing issues in the development of lightweight solution for a vehicle frontal bumper, in: Procedia Eng., 2014: pp. 77–84. https://doi.org/10.1016/j.proeng.2014.11.129.

WORLD EXPERIENCE IN THE USE OF EXCESS SEWAGE SLUDGE

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Highlight

- Precipitation of urban wastewater poses a danger of the spread of pollutants into the environment.
- Overview of the application of urban wastewater sediments and methods of their disinfection.

Abstract

The world experience of neutralization and disposal of excess sludge of urban sewage is considered. The sludge generated during the technical treatment of municipal wastewater is dangerous, has low dehydration, the percentage of moisture is more than 96%, contains some pathogenic and organic substances, as well as heavy metals. In the Mangystau region of Aktau (Kazakhstan) at a sewage treatment plant, sewage sludge is mainly accumulated on silt sites after minimal treatment. The main directions of neutralization and disposal of excess sludge used in Asian and European countries are generalized. For example, while authors from China conducted research on ultrasonic chemical treatment of urban sludge and drying by artificial methods, authors from Europe paid more attention to the disposal of excess sludge from municipal wastewater, in the form of road surface additives, cement strength additives or modified bentonite for further use. Sewage sludge as a safe fertilizer in the national economy. Their advantages and disadvantages are shown, considering environmental and economic efficiency. The advantages of many studies can be indicated by the efficiency of the secondary use of sewage sludge, as well as a significant reduction in the area allocated for the storage of precipitation data.

The disadvantages of these studies can indicate significant economic and time costs, which are ultimately compensated by the positive results of their secondary use.

Keywords
Excess sludge; disposal; neutralization technology; sludge maps; recovery.

Introduction

Excess municipal sewage sludge, an inevitable by-product of municipal wastewater treatment, is a major issue in many countries due to its increasing volume and the impact associated with its disposal. According to a European Commission report published in 2022, 36% of excess sewage sludge available in the countries of the European Union is applied to agricultural land. In the EU countries, the problems of recycling excess sludge from urban wastewater are regulated by the Sewage Sludge Directive 86/278/EEC1. This directive allows the use of sediment in agriculture, strictly monitors the issues of reducing the negative and harmful effects on environmental components and public health. This document establishes permissible concentrations of heavy metals in sediments and in the soil where they are introduced – cadmium, copper, nickel, lead, zinc and mercury. The requirements of the sludge directive have been implemented in the legislation of all EU countries, and many of them have more stringent conditions for their use.

Despite the permissibility of applying sewage sludge to soils, many European countries use incineration methods. Sludge incineration is regulated by the EU Industrial Emissions Directive 2010/75/EU (IED), which sets fixed limits for emissions from waste incineration plants (including sewage sludge) [1]. Sludge incineration on the territory of the Republic of Kazakhstan, both separately and in combination with individual waste is not carried out. Due to the global demand for organic waste and renewable energy sources, sewage sludge can become one of the available and in-demand resources in achieving this goal. It can be used as an energy source to provide the population with energy and heat, using both traditional and new types of technologies. Also, the sediment can be used as fertilizer and land reclamation if an effective technology is used. In this case, the use of sediment is more economically rational compared to incineration, disinfection or burial. Potential environmental improvements to existing solutions include reducing greenhouse gas emissions, improving soil conditions, and reducing the use of fossil fuels. The economic potential is to compensate for the costs associated with traditional waste treatment methods. In order to achieve the goal of wastewater treatment, it is necessary to manage sewage sludge more carefully, not only during the process, but also after their removal from treatment facilities. The new strategies should fit into the trend of eco-innovations in order to fulfill the basic concept of the European Commission strategy "reduce, reuse, recycle", which is currently understood as the most preferred hierarchy of waste management. After cleaning, the sediments are a biological mixture containing organic substances (human waste, food waste), dead and living microorganisms, including pathogenic, inorganic and organic toxic pollutants (trace elements of metals, polycyclic aromatic hydrocarbons).

A certain amount of sludge is regularly recycled in the process of treatment facilities in order to optimize operations. In the case when the raw sludge at the outlet of the treatment facilities contains approximately 95-97% of water, various methods of disinfection and dehydration are necessary for their further use as a useful solid biomaterial. More modern and modernized types of technologies should ensure the processing of organic substances and reduce the potential risk, with the absence of pollutants. Sludge treatment costs account for more than 50-55% of all operating costs at wastewater treatment plants, despite the fact that sewage sludge accounts for several percent of the total volume of treated wastewater. According to the technological regulations 30.0 thousand m^3/day of household, industrial and storm water wastewater are processed daily at the sewage treatment plant "Caspian zhylu arnasy" of the Mangystau region, which are supplied for cleaning by the general water disposal system, and the actual amount of sewage precipitation reaches almost 11 thousand tons/year [2].

Due to the annual increase in the population of the Mangystau region, the volume of waste generated, including excess activated sludge of urban wastewater, is also increasing. The resulting secondary sediments are divided into the following main categories: organic sediments of mineral structure and activated sludge. Before dehydration, organic sludge leads to normal fermentation or stabilization, as well as thermosetting effects. The technological scheme of preparation, processing and subsequent dewatering of organic sediments and activated sludge usually includes the following stages: preliminary pressing, dehydration, thermal drying (burning). To reduce the moisture content of the sludge, including active sludge it is pressed [3]. In Kazakhstan

with a warm climate and hot summers, natural drying can be successfully ap-plied for their dehydration, which is currently used at wastewater treatment plants (WTP) in Aktau (Figure 1).

Figure 1. Photo of the general view of the sludge platform. *Source: Own.*

In recent years, a large number of scientific works appeared on the analysis of the experience of neutralization and disposal of excess sludge accumulated to date. China, Malaysia, India and Europe pay close attention to the problem of neutralization and disposal of excess sludge. Zhang Zongge [4], Yuanjun [5], Li Aimin [6] studied the air temperature and flow rate on the rate of sludge drying, conducted research on the effect of sludge morphology on water separating properties. Yi et al. [7], through the influence of solar dryers, studied the intensity of solar radiation. When solar drying excess sludge, there are several factors that affect the drying rate of the sludge. It was concluded that with greater exposure to solar radiation, the residual moisture content of the sediment is much less. The test results are shown in Figure 2.

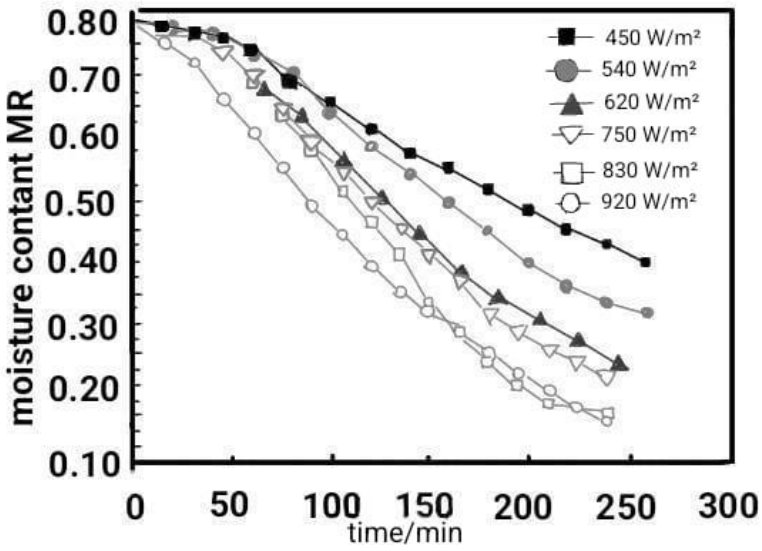

Figure 2. Changes in the water content in the sediment at different solar radiation intensity in an open solar drying system. *Source: Own.*

In this case, the results showed that the main factors in the solar greenhouse were the temperature and air humidity influencing the drying rate. There is no definite pattern between the change in drying rate and moisture content. Lei Haiyan [8,9] carried out experiments on drying excess sludge using home-made mixed solar dryers conducted a pilot study on sludge drying. The results of the experiment indicate the main factors that

influenced the drying process of the sludge. These are sediment deformation, temperature, speed and intensity of solar radiation. According to the experiments carried out on the physical and mechanical properties and chemical composition of Zabelska-Adamska [10], they indicate the possibility of using ash residues from excess sludge from municipal wastewater as a material for environmentally friendly products in civil engineering. The ash formed during the experiment indicates compliance with the norms and sanitary requirements necessary for the composition of road embankments.

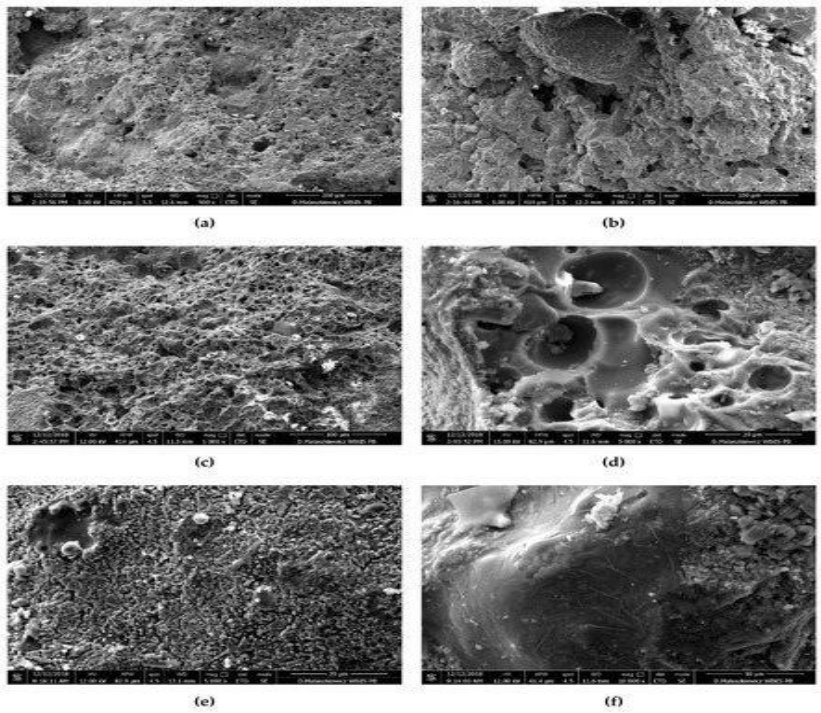

Figure 3**.** Images of porous sewage sludge ashes obtained on a scanning electron microscope (SEM): (**a**) general view of smooth and porous surface 500×, (**b**) porous natural surface 1000×, (**c**) porous fracture surface 1000×, (**d**) silica SiO_2 5000×, (**e**) secondary hematite Fe_2O_3 5000×, (**f**) quartz glass SiO_2. *Source: Own.*

Researchers pay great attention to the processes of sludge dewatering, considering the reduction of moisture content as the leading element in its disposal. Dehydration can be carried out by extensive and intensive methods. The first includes the processes of natural compaction and drying, the second – hardware methods of dehydration with additional effects on the sediment: on centrifuges, chamber and belt filter presses, gravity dehydration in geotubes [11]. According to the calculations of the manufacturer, the Geotube technology has an advantage over other methods of dehydration: the cost of sludge dehydration is 20-30% lower than with the use of apparatuses; absence of complex elements; aesthetics; absence of flooding by precipitation; the possibility of sludge dehydration, temporary storage or permanent burial at the place of its formation; low power consumption [12].

It is known that sewage sludge is an organogenic substrate containing biogenic elements (nitrogen, phosphorus, potassium, and their compounds) in concentrations comparable to traditional organic fertilizers. Therefore, both in scientific literature and in economic activity, great attention has always been paid to the issue of rational use of the biological potential of sewage sludge, its rational use. Silt sediments contain up to 40% organic and, accordingly, up to 60% mineral matter in terms of dry mass. A characteristic feature of sewage sludge is the high protein content. They also contain trace elements (heavy metals), which in adequate concentrations are vital for the development of plants, but in high concentrations they cause the toxicity of silt sediments. Heavy metals (trace elements) necessary for the growth of microorganisms can be divided into groups: elements that are usually necessary for growth (essential) — Ca, Mn, Fe, Co, Cu, Zn; elements that are rarely necessary for growth (nonessential),— Ba, Na, Al, Si, Cl, V, Cr, Ni, As, Se, Mo, Sn, I. The composition of the sludge of treatment facilities was determined based on the Method of measuring the mass concentration of heavy metals in activated sludge samples by the fluorometric method using the liquid analyzer "Fluorat- 02", M 01-26-2001, STB ISO 11885-2011. Sampaio et al. [13] says that the composted surplus sludge from municipal wastewater is an organic fertilizer that was obtained from the treatment of municipal wastewater at wastewater treatment plants. It is possible

that excess sludge from municipal wastewater contains a significant amount of potentially toxic elements and pathogenic agents (e.g., helminth eggs, protozoan cysts, E. coli, etc.). However, composting can significantly reduce the pathogenic load and can stabilize potentially toxic elements due to organometallic formation, so that potentially toxic elements are no longer available to plants. In addition, this method stabilizes organic matter, as a result of which the product can be safely used and classified in accordance with national and international standards as an organic fertilizer. In fact, sewage sludge contains a large amount of organic substances and plant nutrients, including nitrogen, phosphorus and trace elements. Several studies by Hernandez, Yakubus, and Florentino [14–16], reported the benefits of sediment for the physical, chemical and biological properties of the soil. Thus, Meng, et al. [17], believe that composting is a sustainable solution for companies engaged in the disposal of sludge from water treatment plants.

The Brazilian Government recently adopted Resolution No. 498/2020, Ministérioda Agricultura, Pecuária e Abastecimento/Secretariade Defesa Agropecuária. 2020 [18], which establishes rules for the use of sewage sludge in agriculture. Therefore, the introduction of sewage sludge into the soil must meet the agronomic criteria of the resolution. Accordingly, sewage sludge is considered an organic fertilizer if it complies with the standards established by the Ministry of Agriculture, Livestock and Food (MAPA), Regulatory No. 61/2020, Ministério da Agricultura, Pecuária e Abastecimento. 2020, Instrução Normativa No. 61, July 08, 2020 [19,20], which sets thresholds for pathogenic organisms and concentrations of potentially toxic elements.

Research Xu [21] showed that, at present, ultrasonic technology is widely used in the treatment of excess sludge, as it has a high decomposition rate and efficiency in use. He carried out experiments in the study areas, applying ultrasonic chemical treatment of excess sludge. An experiment using ultrasound revealed the destruction of the structure of sediment flakes and cell walls, the release of intracellular organic substances, and the acceleration of the hydrolysis process. It turned out that ultrasound is able to improve the processes of sedimentation and dehydration of sludge, and the ultrasonic wave produces a spongy effect on excess sludge. This facilitates the flow of water through the channel from the surface of the wastewater, which leads to agglomeration of the sludge particles and increases the particle size. It has also been found that ultrasound promotes the coagulation process, improves the activity of the sewage sludge and increases the efficiency of the anaerobic digestion process and the final production of biogas. The sonication process of the cationic polyacrylamide leads to a weakening of the outflow between the particles and destabilizes the sludge flock. And also, the adsorption process and the binding action of the flocculant accelerates the agglomeration of the sludge particles, while the water in the sediment is separated to be converted into free water. In this case, this improves the dewatering process and also reduces the amount of moisture in the filter cake.

The behavior of thin-layer drying of urban sewage sludge in a laboratory convective dryer with forced hot air supply using ultrasound transmitted through the air was investigated by San, et al. [22] at hot air temperatures from 70°C to 130°C. The kinetics of drying only in the convective process was compared with the kinetics of the process using ultrasound at three ultrasound powers (30, 90, 150 Watts). Average drying speeds over the entire drying temperature range at ultrasound power of 30, 90 and 150 W increased by about 22.6%, 27.8% and 32.2% compared with convective drying alone (without ultrasound). As the temperature increased from 70°C to 130°C, the maximum increase in the coefficients of effective diffusion of sewage sludge moisture was observed in both periods of speed reduction at an ultrasound power of 30 W compared to the other two high powers. In the range between ultrasound power from 0 to 30 Watts, the effect of power on the drying rate was significant, while its effect was not obvious over 30 Watts. Thus, the low ultrasound power can simply be set during the drying process. The values of the apparent activation energy in the first period of speed reduction decreased from 13.52 to 12.78 kJ mol^{-1} and from 17.21 to 15.10 kJ mol^{-1} in the second period of speed reduction with an increase in ultrasound power from 30 to 150 watts.The values of the apparent activation energy for two periods of speed reduction using ultrasound were less than with convective drying with hot air only. According to other studies by Salim et al. [23], sewage sludge was used by including it in baked clay bricks to obtain the properties and leaching ability of heavy metals. The use of sewage sludge in baked clay bricks can lead to the production of bricks of good quality.Thus, the recycling of waste in the production of bricks seems to be a viable solution to the problem of environmental pollution, as well as an economical option for designing green construction [24].

Latosinskaya et al. [25] proposes to convert the sludge into synthetic zeolites for the purpose of further disposal of sewage sludge ash. Zeolite P can be noted as one of the known types of zeolites. Zeolite P is synthesized from sewage sludge ash by chemical conversion. The excess sludge ash conversion process is carried out by activation

at temperatures of 60°C and 90°C, crystallization temperatures of 60°C and 90°C, a crystallization time of 72 hours and an SSA:NaOH ratio of 1:1.4. After the zeolitization process, changes in the surface of the ash particles, identification of crystallized phases, cation exchange capacity and specific surface area were monitored. The activation temperature and crystallization at a temperature of 90°C were the most optimal conditions for the synthesis of zeolite P. The described method of ash formation of sewage sludge assumes to obtain a material suitable for use. Górka et al. [26] carried out studies on anaerobic co-digestion of sludge from municipal wastewater treatment plants. During the processes of coagulation, ozonation and backwashing of fast anthracite filters, an aqueous precipitate was formed. Its characteristics and properties depend on the quality of raw water, treatment methods, as well as the types of chemicals used and their doses. According to the Polish law of December 4, 2012 (Journal of Laws 2013, point 21), water sludge is to be treated as hazardous waste. According to the results of the experiments of these authors, it was proposed to increase the production of biogas due to the joint fermentation of wastewater and aqueous sludge. The results of these studies by the authors can serve as a basis for developing a methodology for monitoring and sludge disposal.

Czechowska-Kosacka et al. [27] investigated sewage sludge and its mixtures with fly ash for use as an additive in the production of building materials. The experiment was carried out by the author using X-ray diffraction. Using a scanning electron microscope, the shape, morphology of the samples, and the chemical composition in the microarray were determined. Sewage sludge ash can be used for construction purposes. In the studied experimental data, an increased content of anhydrite and rock-forming calcite is noted in relation to the sludge. To determine the percentage of waste added in the production of building materials, additional strength tests of the resulting material are required.

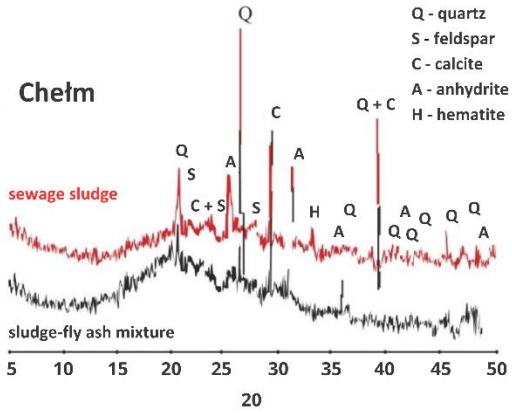

Figure 4. X-ray diffractogram of sewage sludge from the treatment facilities "Belavin" in Chelm and a mixture of sludge and fly ash. *Source: Own.*

Kovalenko et al. [28] carried out certain experiments in order to obtain a more durable and inexpensive road construction material, the basis of which is sewage sludge ash reinforced with a mineral binder. During the experiments, the characteristics of the strength of the mixture of ash with sludge and ash with cement were determined, as well as the search for optimal dosages of binders. The results of a comparative analysis of the economic efficiency of using a mixture of ash from the incineration of sewage sludge, reinforced with nepheline sludge, and traditional road construction materials turned out to have high strength and modulus of elasticity. They belong to strength classes from M20 to M100. The resulting building material (ash mixed with binders (cement, nepheline sludge)) could replace conventional building material in road construction technology. In the process of use, it would be beneficial, both in terms of physical, mechanical and economic indicators, if it is used in optimal dosages Figure 5.

The regression equations for the experimental curves are given below: The structure formation time is 14 days. Rcompr= -0.624x4 + 8.4342x3-37.286x2 + 64,456x-27,392; R2 = 0,9821. The formation time of the structure is

28 days. Rcompr = -0,5271x4 + 6,9042x3-29,16 x2 + 48,48x-17,25; R2 = 0,9987.

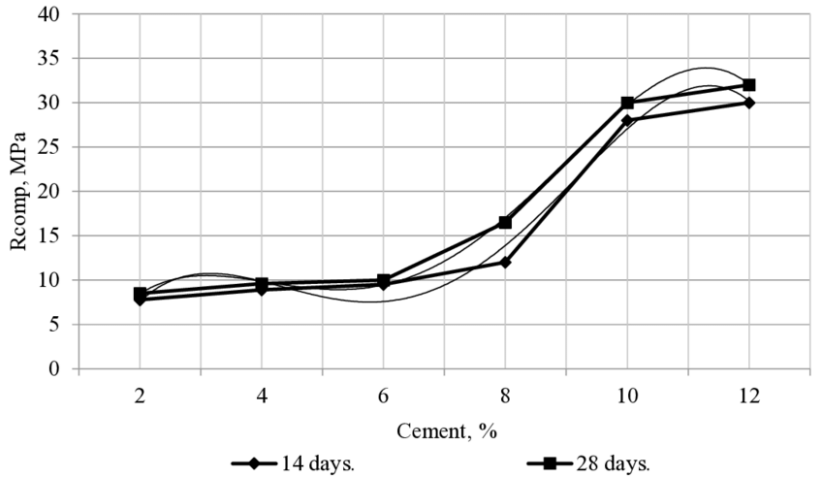

Figure 5**.** Graphical dependence of the compressive strength of cement-reinforced ash samples on cement doses in different periods of their structure formation. *Source: Own.*

Gu et al. [29] used a combination of a solar drying bed and conventional solar drying technology to perform an experiment. A solar collector and a solar drying layer were used to convert solar energy into thermal energy. In this case, excess sludge is heated and dried under the influence of solar heat, while the moisture in the sediment evaporates as much as possible in a natural way. This result is an excellent opportunity to conduct new types of research and development of efficient, environmentally friendly and energy-saving systems for treating sludge resources. The source of heat is renewable energy - solar energy. The combination of solar drying solar drying bed and traditional hot air drying can effectively reduce energy consumption and operating costs. As shown in the figure, the drying chamber was divided into three layers. Hot air is supplied in the upper layer, moist excess sludge is introduced in the middle layer, and a hot water coil is used in the lower layer to dry the sludge. The drying process is a process of heat and mass transfer with convective and radiative heat transfer Figure 6.

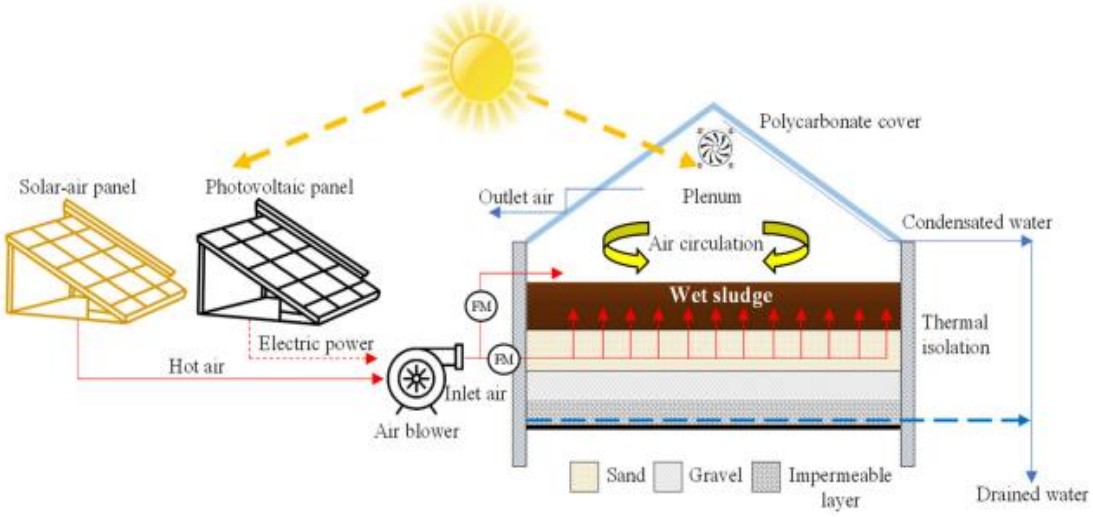

Figure 6. Schematic view of a static solar greenhouse. *Source: Own.*

After analysis and comparison with traditional energy drying, it was found that drying 97.5 kg of sewage sludge will save 79% of energy, save 12.84 kg of standard coal, reduce 32 kg of carbon dioxide and 1.284 kg of sulfur dioxide. Barrett et al. [30] identified the predominant antibacterial compounds affecting E coli from Ontario sewage sludge consisting of thousands of unknown compounds. Analysis of the mass balance of the active substance confirmed that triclosan explains the majority (58-113%) of the inhibitory effects of sediment extracts.

This study showed that triclosan is the predominant antibacterial compound in sewage sludge that affects E. coli, despite the simultaneous use of many other antibiotics and non-antibiotics. Chenga et al. [31] in their research studied the viability of modified bentonite as a conditioning agent for the stabilization of heavy metals (i.e., Cu, Zn, Cr, Pb and Cd) and the preservation of nutrients (i.e., total nitrogen (TN). Total phosphorus (TP), available nitrogen (available N) and Olsen phosphorus (Olsen-P) in sewage sludge for agricultural use, the test results are shown in Figure 7.

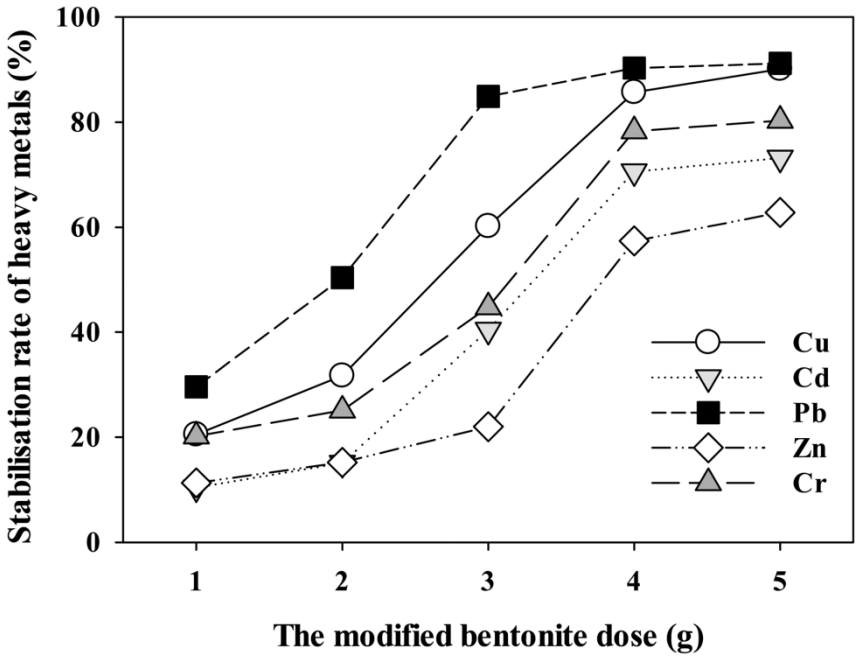

Figure 7**.** The degree of stabilization of the content of heavy metals in the sewage sludge (weight of each sample = 50 g) depending on the dose of modified bentonite (1-5 g). *Source: Own.*

The results of the research were as follows: modified bentonite stabilized heavy metals and preserved nutrients in the sewage sludge; an optimal ratio of a mixture of conditioned sewage sludge with soil (1:2) for agricultural use was proposed; modified bentonite allowed the use of sewage sludge as fertilizer in agriculture. Pancevska et al. [32] conducted research on the conversion of sewage sludge into activated carbon. The conversion of sewage sludge into activated carbon based on its high content of organic components not only solves the problem of disposal of sewage sludge, but also turns solid waste into a useful material in the production of adsorbent for wastewater treatment. In this study, activated carbon based on sludge was obtained using sewage sludge from the Volkovo Wastewater Treatment Plant in Skopje by chemical activation using a 25% $ZnCl_2$ solution and carbonation at a temperature of 600 °C for 50 minutes. The resulting activated carbon based on sediment was characterized using a scanning electron microscope, an X-ray diffractometer and well-known standard methods such as ash and moisture content, as well as adsorption capacity using the iodine number method. The resulting activated carbon based on sediment has a macroporous structure and interchangeable cations, which makes it suitable as an adsorbent for wastewater treatment, the test results are shown in Figure 8.

Sewage sludge generated at the Volkovo treatment facilities in Skopje, Republic of North Macedonia has been successfully converted to activated carbon based on sludge using the chemical activation method. The resulting activated carbon based on sediment was characterized using a scanning electron microscope, X-ray diffractometer, iodometric method and ash and moisture content. The results showed that activated carbon based on sediment has a macroporous structure and interchangeable cations, which makes it suitable as an adsorbent for wastewater treatment. The results also showed that activated carbon based on sediment has a higher ash content, bulk density and humidity, while the value of the iodine number is within the normal range.

The results of research by Verbovsky et al. [33] on the intensification of existing mechanical methods for treating sediments. An effective way to intensify the process of sewage sludge dehydration is electrical

dehydration, which involves the use of an electric field during mechanical sludge dehydration. The process of electrical dehydration will not only reduce the moisture content of sediments to 20...40%, but also reduce the concentration of heavy metals and pathogens in sediments. The main goal of the authors is to study the possibility of electric dehydration of activated sludge from secondary sedimentation tanks of urban sewage treatment facilities in the city of Lvov (Ukraine). Scientists used empirical research methods; the test results are shown in Figure 9.

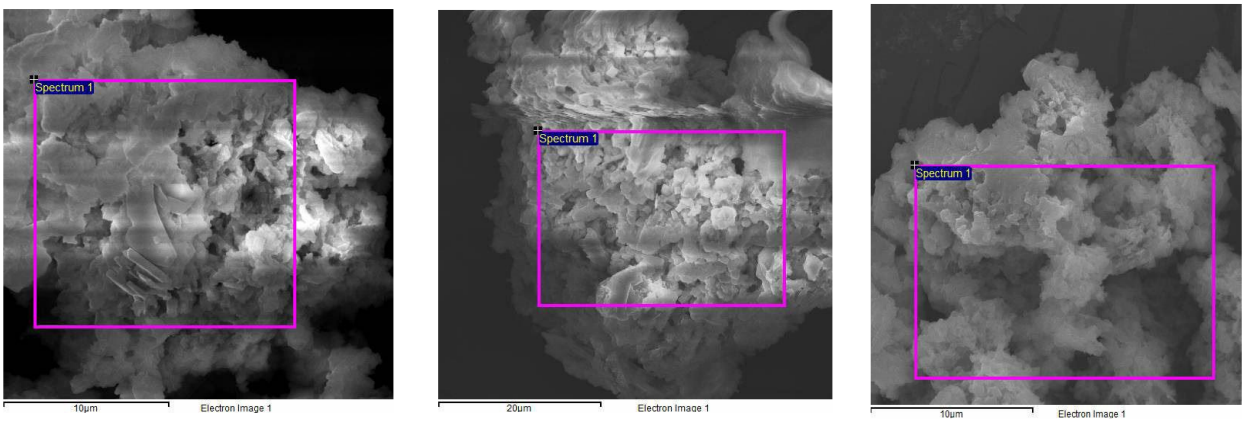

Figure 8. Micrographs of a sample for EDS analysis. *Source: Own.*

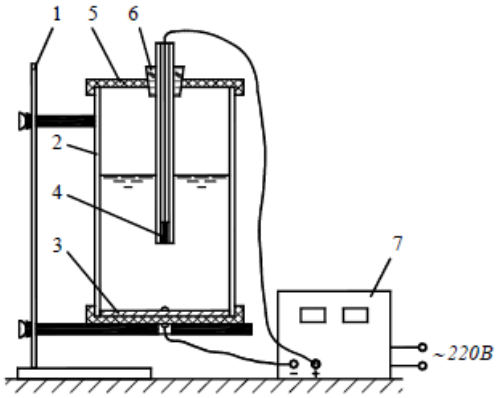

Figure 9**.** The laboratory-scale device for electro-dewatering of sewage sludge scheme: 1 – laboratory tri-pod; 2 – cylindrical capacity; 3 – cathode; 4 – anode; 5 – lid; 6 – sealing insert; 7 – electric-current rectifier. *Source: Own.*

A laboratory stand was designed for electro-dehydration of sewage sludge. The activated sludge with a moisture content of 98% was examined. It is shown that the effect of dehydration of activated sludge, depending on the duration of its treatment, is an S-shaped curve resembling a kinetic autocatalytic reaction with three periods: induction, basic, damping. The possibility of electro-dehydration of sewage sludge with a maximum dewatering effect of 60% is proved. Therefore, it is proposed to perform mechanical dehydration of urban wastewater sediments using an electric field. Ab Latif et al. [34] consider the use of sewage sludge ash as a replacement for cement in concrete production. Sewage sludge ash is a powdery material containing a high percentage of SiO2, Al2O3, Fe2O3, CaO, P2O5 and SO3 and is moderately reactive in terms of pozzolanicity. Many researchers have incinerated sewage sludge at temperatures ranging from 600°C to 900°C to produce sewage sludge ash. Partial replacement of cement with sewage sludge ash contributed to an increase in the compressive and bending strength of concrete. Meanwhile, replacing 5% of sewage sludge ash by weight of cement was considered to be the optimal content to obtain the best mechanical performance of concrete. In addition, concrete workability improved after 28 days with the addition of sewage sludge ash.

Impact

The accumulation of precipitation at wastewater treatment plants on the one hand complicates their production activities, causes the need to expand the network of sludge maps for the storage and disposal of sewage sludge, and on the other hand, potential sources of pollution of the biosphere, hydrosphere, lithosphere and alienation

of scarce land resources arise in the epicenter and nearby territories of cities with the accumulation of sewage sludge. Analysis of methods of neutralization and disposal of sewage sludge shows the effectiveness of their use in various fields of activity. The use of these methods leads to a reduction in waste disposal areas, minimizing their impact on the environment, reducing the volume of waste storage, and economically advantageous ways of their secondary use.

Conclusion

The problem of disposal of sewage sludge remains unresolved today. The relevance of this problem is caused on the one hand by active processes of urbanization, on the other hand by the emergence of new scientific data on the processes of interaction of precipitation components with the environment. The analysis of scientific publications indicates the need for a comprehensive approach to the disposal of excess sludge, considering specific conditions and factors. The main trends in the disposal of sewage sludge in the review of research by various scientists were: the use of sludge ash as additives in road construction; partial replacement of cement with ash from sewage sludge contributed to an increase in the compressive and bending strength of concrete; activated carbon based on sediment has a macroporous structure and interchangeable cations, which makes it suitable as an adsorbent for wastewater treatment; electro-dewatering technology allows to reduce the humidity of precipitation to 20...40%, reduce the concentration of heavy metals and pathogens in precipitation; modified bentonite stabilized heavy metals and preserved nutrients in sewage sludge; the use of ultrasound can improve the activity of excess sludge and increase the efficiency of the anaerobic digestion process and the final production of biogas. The combination of a solar drying layer and traditional solar drying technology can be noted as the most promising for the Mangystau region (Aktau city). There are about 3329.47 hours of sunlight in Aktau during the year, which is an excellent prospect for using a solar greenhouse. Also, with greater economic efficiency, it is possible to use sludge ash as additives in road construction, since in the Mangystau region there is a low cost of natural gas needed for burning sewage sludge. Also, due to the increase in urbanized territories, there is an urgent need to build motor roads to improve the quality of life of the local population.

Conflict of interest

There are no conflicts to declare.

Acknowledgments

This article is a review. The article indicates technologies for the recycling of sewage waste

References

[1] U.S. Environmental Protection Agency, (2023).
[2] The Kazahkstan project “Caspian zhylu arnasy” of the Mangystau region, 2018-2022, (2022).
[3] K. Jumasheva, S. Syrlybekkyzy, A. Serikbayeva, F. Nurbaeva, A. Kolesnikov, Study the composition and environmental impact of Sewage Sludge, J. Ecol. Eng. 24 (2023) 315–322. https://doi.org/10.12911/22998993/158544.
[4] Z. Zonghe, N. Baolian, L. Haiyan, The trial of sludge dewatering and drying by solar energy, Water and Wastewater, China. (2003) 111–113.
[5] Y. Jun, F. Haojie, S. Shanbin, et al., The experimental study of sewage sludge drying fundamental characteristics, Water Wastewater Eng. (2008) 185–188.
[6] A. Li, Y. Qu, Z. Yang, et al., Surface configuration and moisture transference during sewage sludge drying, J. Chem. Ind. Eng. (2018) 1011–1015.
[7] A. Yi, L. Jianzhong, et.al., The effects of solar radiation intensity on the drying properties of sludge, Renew. Energy. (2019) 715–721.
[8] L. Haiyan, L. Weiyi, Z. Zheng, Experimental study on solar sludge drying, ActaEnergiae Solaris Sin. (2012) 479–482.
[9] S. Kaifeng, L. Yanfeng, W. Dengjia, E. Al., Study on the relationship between outdoor temperature and solar radiation, Civ. Eng. Environ. Eng. 5 (2015) 116–121.
[10] K. Zabielska-Adamska, Sewage sludge bottom ash characteristics and potential application in road embankment, Sustainability. 12 (2019) 39. https://doi.org/10.3390/su12010039.
[11] P.I. Pogozhev, Geotube and installation for separation of suspensions by filtration using a geotube, Patent №0002712603-29.01.2020., 2020.
[12] NPC Geotube, http://geotub:ru/manufacture.
[13] T.F. Sampaio, I.A. Guerrini, X.L. Otero, F.M. Vazquez, J.C. Bogiani, F.C. Oliveira, J.L. Gava, M.A. Ciol, K.M.

Littke, R.B. Harrison, The impact of biosolid application on soil and native plants in a degraded Brazilian atlantic rainforest soil, Water, Air, Soil Pollut. 227 (2016) 1. https://doi.org/10.1007/s11270-015-2689-7.

[14] T. Hernández, C. Chocano, J.L. Moreno, C. García, Use of compost as an alternative to conventional inorganic fertilizers in intensive lettuce (Lactuca sativa L.) crops—Effects on soil and plant, Soil Tillage Res. 160 (2016) 14–22. https://doi.org/10.1016/j.still.2016.02.005.

[15] M. Jakubus, E. Bakinowska, Visualization of long-term quantitative changes of microelements in soils amended with sewage sludge compost evaluated with two extraction solutions, Commun. Soil Sci. Plant Anal. 49 (2018) 1355–1369. https://doi.org/10.1080/00103624.2018.1464177.

[16] A.L. Florentino, A. d. V. Ferraz, J.L. de M. Gonçalves, V. Asensio, T. Muraoka, et.al., Long-term effects of residual sewage sludge application in tropical soils under Eucalyptus plantations, J. Clean. Prod. 220 (2019) 177–187. https://doi.org/10.1016/j.jclepro.2019.02.065.

[17] L. Meng, W. Li, S. Zhang, X. Zhang, Y. Zhao, L. Chen, Improving sewage sludge compost process and quality by carbon sources addition, Sci. Rep. 11 (2021) 1319. https://doi.org/10.1038/s41598-020-79443-3.

[18] P. e A. de D.A. Ministério da Agricultura, The Brazilian Government recently adopted Resolution No. 498/2020, (2020).

[19] P. e A. de D.A. Ministério da Agricultura, Resolução nº 498, de 19 de Agosto de 2020. https://www.scribd.com/document/585203764/RESOLUCAO-Nº-498-DE-19-DE-AGOSTO-DE-2020.

[20] P. e A. Ministério da Agricultura, InstruçãoNormativa no 61, de 08 de Julho de 2020. http://www.in.gov.br/web/dou/-/instrucao-normativa-n-61-de-8-de-julho-de-2020-266802148.

[21] X. Xu, D. Cao, Z. Wang, J. Liu, J. Gao, M. Sanchuan, Z. Wang, Study on ultrasonic treatment for municipal sludge, Ultrason. Sonochem. 57 (2019) 29–37. https://doi.org/10.1016/j.ultsonch.2019.05.008.

[22] M.K. Sun, C.Y.V. Huang, Evaluation of the characteristics of thin-layer drying of urban sewage sludge using air-ultrasonic convection with hot air, Ultrasound Sonochemistry. 34 (2017) 588–599.

[23] N.S. Abdul Salim, A. Abdul Kadir, M.A. Kamarudin, M.H. Fadzli Zaidi, M.M.A.. B. Abdullah, Investigation on properties and leachability of sewage sludge from wastewater treatment plant incorporated in fired Clay Brick, IOP Conf. Ser. Mater. Sci. Eng. 374 (2018) 012096. https://doi.org/10.1088/1757-899X/374/1/012096.

[24] A treatment plant built into a baked clay brick. Environment IR 2018, IOP Conf. Ser. Mater. Sci. Eng. 374. (2018) 1–9.

[25] J. Latosińska, Synthesis of zeolite P from sewage sludge ash, E3S Web Conf. 108 (2019) 02008. https://doi.org/10.1051/e3sconf/201910802008.

[26] J. Górka, M. Cimochowicz-Rybicka, Possible co-fermentation of water and sewage sludge, E3S Web Conf. 17 (2017) 00025. https://doi.org/10.1051/e3sconf/20171700025.

[27] A. Czechowska-Kosacka, Application of sewage sludge for the production of construction, MATEC Web Conf. 252 (2019) 05025. https://doi.org/10.1051/matecconf/201925205025.

[28] O. Zubova, V. Siletskiy, D. Kulik, T. Kovalenko, M. Naskovets, Research in the field of using of ash from the incineration of sewage sludge, treated with mineral binders, for forest road construction, E3S Web Conf. 222 (2020) 01007. https://doi.org/10.1051/e3sconf/202022201007.

[29] Z. Gu, J. Yang, J. Liu, L. Tao, Y. Zhang, L. Huang, Study on sewage sludge drying system with built-in solar drying bed, E3S Web Conf. 237 (2021) 01041. https://doi.org/10.1051/e3sconf/202123701041.

[30] H. Barrett, J. Sun, Y. Gong, P. Yang, C. Hao, J. Verreault, Y. Zhang, H. Peng, Triclosan is the predominant antibacterial compound in Ontario sewage sludge, Environ. Sci. Technol. 56 (2022) 14923–14936. https://doi.org/10.1021/acs.est.2c00406.

[31] Y. Cheng, K. Chon, X. Ren, M. Li, Y. Kou, M. Hwang, K. Chae, Modified bentonite as a conditioning agent for stabilising heavy metals and retaining nutrients in sewage sludge for agricultural uses, Water Sci. Technol. 84 (2021) 2252–2264. https://doi.org/10.2166/wst.2021.450.

[32] V. Pancevska, A. Zendelska, Preparation and characterization of sludge-based activated carbon, Resour. Technol. 16 (2022) 61–67. https://doi.org/10.46763/NRT22161061p.

[33] O. Verbovskyi, V. Orel, O. Matsiyevska, D. Derkach, Sewage sludge dewatering by electric field, Probl. Water Supply, Sewerage Hydraul. (2022) 16–25. https://doi.org/10.32347/2524-0021.2022.40.16-25.

[34] A. Ab Latif, A. Nazarudin, M. Noor Safwan, Use of sewage sludge ash as a cement replacement in concrete: A review, Gading J. Sci. Technol. 3 (2020) 59–65.

EVOLUTION AND INNOVATION OF HEDGE FUND STRATEGIES: A SYSTEMATIC REVIEW OF LITERATURE AND FRAMEWORK FOR FUTURE RESEARCH

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Highlight
This systematic review explores the dynamic evolution and innovative trends within hedge fund strategies. It provides a comprehensive understanding of their historical development and contemporary shifts. By identifying research gaps and offering a structured framework for future investigations, this study serves as a valuable resource for both scholars and practitioners, facilitating advancements in the field.

Abstract
Hedge funds are a dynamic and heterogeneous segment of the financial industry that employs various strategies to generate returns and manage risk. Despite their growing importance and impact on the global economy, hedge funds remain largely unregulated and opaque, posing challenges for researchers and regulators alike. This paper provides a systematic review of the academic literature on hedge fund strategies, covering their institutional, historical and performance characteristics; their purpose and effectiveness in achieving balanced portfolios; and the relationship of returns to manager skill, style, size and other factors. The paper also proposes a framework for future research on hedge fund strategies.

Keywords
Hedge fund strategies; innovation; risk management; performance.

Introduction
Hedge funds are a type of alternative investment that aims to generate returns that are uncorrelated with the market. Hedge fund strategies are diverse and dynamic, evolving over time in response to changing market conditions, investor preferences, and regulatory frameworks. In this paper, we review the literature on the

evolution and innovation of hedge fund strategies, focusing on three main aspects**:** the sources of hedge fund returns, the drivers of hedge fund innovation, and the implications of hedge fund innovation for investors and regulators. We identify four main sources of hedge fund returns: market risk premia, factor risk premia, alpha, and liquidity provision. We discuss how hedge fund managers exploit these sources through various techniques, such as leverage, short selling, derivatives, arbitrage, and market timing. We also examine the factors that motivate hedge fund managers to innovate their strategies, such as competition, regulation, investor demand, and technological advancement. We highlight the benefits and challenges of hedge fund innovation for investors and regulators, such as diversification, performance, risk management, transparency, and systemic risk. The aim of this research is to examine how hedge fund strategies have evolved over time and how they have adapted to changing market conditions and investor preferences. The specific objectives of this research are:

- to review the literature on the classification and performance of hedge fund strategies and identify the main drivers and challenges of hedge fund innovation.
- to analyze the historical data on hedge fund returns, risk, and exposures, and detect the patterns and trends of hedge fund strategy evolution.
- to develop a framework for assessing the innovation potential and sustainability of hedge fund strategies and apply it to some of the emerging and niche strategies in the market.
- to provide insights and implications for hedge fund managers, investors, regulators, and researchers on how to foster and evaluate hedge fund innovation.

Literature review

Hedge funds are investment vehicles that employ a wide range of strategies to generate returns for their investors. The term "hedge fund" was coined in the 1940s by Alfred Winslow Jones, who pioneered the use of short selling and leverage to hedge market risk [1]. It was originally coined to describe funds that used hedging techniques to reduce market risk, but over time, hedge funds have evolved and diversified to include various types of strategies, such as long/short equity, global macro, event-driven, relative value, and many others. Since then, hedge fund strategies have evolved and diversified to exploit various sources of alpha, such as market inefficiencies, arbitrage opportunities, behavioral anomalies, and macroeconomic trends [2]. Hedge fund innovation is the creation and adoption of new strategies, products, or practices by hedge funds that aim to generate superior risk-adjusted returns or meet specific investor needs. Hedge fund innovation can take various forms, such as launching new funds with novel investment objectives or techniques, developing new trading algorithms or data sources, exploiting new market opportunities or inefficiencies, or offering new fee structures or liquidity terms. The evolution and innovation of hedge fund strategies have been driven by several factors, such as changing market conditions, regulatory developments, technological advancements, and investor preferences [3].

The sources of hedge fund returns are not always clear or well understood, however some of the two main sources of hedge fund returns: economic risk premiums and manager skill.

- Economic risk premiums are the rewards that investors receive for taking on certain types of systematic risks that are not easily diversified away. For example, investors who invest in equities expect to earn a higher return than those who invest in risk-free assets, because equities are exposed to market risk. Similarly, investors who invest in small cap stocks expect to earn a higher return than those who invest in large cap stocks, because small cap stocks are exposed to size risk [4]. Hedge funds can exploit these risk premiums by taking long or short positions in various asset classes, sectors, styles, or regions, depending on their views and strategies.
- Manager skill is the ability of hedge fund managers to generate returns that are not explained by economic risk premiums or other common factors. This is also known as alpha, which is the excess return over a benchmark or a hurdle rate. Manager skills can arise from superior security selection, market timing, arbitrage, or trading techniques. Hedge funds can demonstrate their skill by generating positive residual returns after controlling for their factor exposures, as estimated by various models such as MSCI's Fund Model or Fung and Hsieh's seven-factor model [5].

The relative importance of economic risk premiums and manager skill in explaining hedge fund returns may vary across different hedge fund strategies and over time. Some strategies may rely more on capturing risk premiums, such as long/short equity, equity market neutral, or managed futures [6]. Other strategies may rely more on exploiting market inefficiencies or anomalies, such as event driven, convertible arbitrage, or global macro. Moreover, the availability and persistence of risk premiums and alpha opportunities may change depending on market conditions, competition, regulation, or innovation.

Drivers of hedge fund innovation

- Competitive pressure from other hedge funds and institutional investors: Hedge funds operate in a highly competitive market where they need to constantly seek alpha (excess returns) and differentiate themselves from their peers. According to a survey by EY, hedge fund managers cite competition as the top challenge for their business and innovation as the key factor for success. Moreover, hedge funds face increasing demand from institutional investors, such as pension funds and endowments, who have higher expectations for transparency, risk management, and alignment of interests. To attract and retain these sophisticated investors, hedge funds need to innovate in their product offerings, fee structures, and reporting capabilities [7].
- Availability of new data sources and technologies that enable hedge funds to exploit new market opportunities and improve their operational efficiency: Hedge funds have access to a vast amount of data, both traditional and alternative, that can provide insights into market trends, consumer behavior, and company performance. For example, hedge funds can use social media data, satellite imagery, or web scraping to generate trading signals or monitor portfolio companies. Furthermore, hedge funds can leverage new technologies, such as artificial intelligence (AI), machine learning (ML), or blockchain, to enhance their analytical capabilities, automate their processes, or reduce their costs. A study by Brav et al. finds that hedge fund activism leads to an improvement in target firms' innovation efficiency, as measured by patent counts and citations, partly due to the reallocation of innovative resources and the redeployment of human capital.
- Regulatory environment that shapes the rules and standards for hedge fund operations and activities: Hedge funds are subject to various regulations in different jurisdictions that affect their market access, reporting requirements, tax treatment, and investor protection. While some regulations may impose constraints or costs on hedge funds, others may create incentives or opportunities for innovation. For instance, Deloitte (2023) suggests that the adoption of environmental, social, and governance (ESG) criteria by regulators and investors may spur hedge funds to develop new ESG-focused strategies or products. Additionally, some regulations may foster innovation by enhancing market stability, transparency, and efficiency.
- Market opportunities: This refers to the availability and attractiveness of new sources of alpha, or excess returns, for hedge funds. Hedge funds can exploit market inefficiencies, anomalies, or mis-pricings by using sophisticated quantitative models, big data analytics, artificial intelligence, or alternative data sources. Hedge funds can also benefit from market disruptions, crises, or shocks that create volatility and divergence among asset prices [8]. Market opportunities can vary across regions, sectors, and asset classes, depending on the level of development, regulation, and competition of each market.
- Investor demand: This is the preferences and expectations of hedge fund clients, who are typically institutional investors, such as pension funds, endowments, foundations, sovereign wealth funds, or fund of funds. Investor demand can influence hedge fund innovation by shaping the size, structure, fees, liquidity, transparency, and risk-return profile of hedge fund products [9]. Investors can also exert pressure on hedge funds to adopt certain environmental, social, and governance (ESG) criteria, ethical standards, or social impact goals in their investment decisions. Investor demand can vary across regions, sectors, and investor types, depending on the level of sophistication, regulation, and diversification of each investor group.
- Organizational capabilities**:** This refers to the internal resources and processes that enable hedge funds to generate and implement innovative ideas. Organizational capabilities include human capital, which is the talent, skills, and creativity of hedge fund managers and employees; social capital, which is the network, reputation, and relationships of hedge fund managers with investors, peers, regulators, and other stakeholders; and technological capital, which is the hardware, software, and systems that support hedge fund operations. Organizational capabilities can vary across hedge funds depending on their size [3].

The four main sources of hedge fund returns

- Market risk premia: These are the returns that investors earn for taking exposure to broad market movements, such as equity, bond, currency, or commodity markets. These are the most common and well-known sources of returns, and they can be accessed through passive or low-cost vehicles such as index funds or exchange-traded funds (ETFs). However, market risk premia are also subject to significant fluctuations and drawdowns, especially during periods of market stress or crisis. Hedge fund managers can exploit this source of return by taking long or short positions in different asset classes, such as equities, bonds, commodities, currencies, and emerging markets. Hedge fund managers

can also use leverage to amplify their exposure to market risk premium.

- Factor risk premia: These are the returns that investors earn for taking exposure to systematic sources of risk that are not fully explained by market risk premia. These include style factors, such as value, growth, momentum, size, quality, or low volatility; alternative factors, such as event risk, volatility arbitrage, carry trades, or convergence trades; and macro factors, such as term structure, credit risk, or emerging markets. Factor risk premia can be accessed through smart beta strategies or hedge fund strategies that employ systematic rules or models to exploit these sources of return [10]. Factor risk premia can offer diversification benefits and higher risk-adjusted returns than market risk premia, but they can also exhibit cyclicality and non-linearity. Hedge fund managers can exploit this source of return by using derivatives, such as options, futures, swaps, and forwards, to create synthetic exposures to these factors. Hedge fund managers can also use arbitrage strategies to exploit mispricing or inefficiencies between different markets or instruments [11].
- Alpha: This is the return that investors earn for taking exposure to the specific skills of talented managers who can identify and exploit market inefficiencies or mis-pricings. Alpha is often associated with hedge funds that employ discretionary or qualitative approaches to select securities or markets based on fundamental analysis, market insights, or proprietary information. Alpha can offer uncorrelated and superior returns than market or factor risk premia, but it is also the most elusive and difficult to measure source of return. Alpha requires a high degree of manager skill and due diligence, and it can be eroded by competition or changing market conditions [12]. Alpha is independent of any systematic risk factors and represents the true value added by hedge fund managers . Hedge fund managers can exploit this source of return by using various techniques, such as security selection, market timing, tactical asset allocation, and dynamic hedging. Hedge fund managers can also use leverage to magnify their alpha.
- Liquidity provision: This is the return that investors earn for taking exposure to illiquid or complex assets or strategies that require long holding periods, high entry or exit costs, or specialized expertise. Liquidity provision can be accessed through hedge fund strategies that invest in distressed securities, private equity, real estate, infrastructure, or other alternative assets [13]. Liquidity provision can offer higher returns than liquid assets or strategies, but it also entails higher risks and costs. Liquidity provision requires a long-term investment horizon and a high tolerance for uncertainty and volatility.
- Event risk premium: This is the excess return that investors can earn by taking exposure to specific events that affect the value of certain securities or markets. These events include mergers and acquisitions, spin-offs, bankruptcies, restructurings, earnings announcements, regulatory changes, and geopolitical shocks. Hedge fund managers can exploit this source of return by using event-driven strategies, such as merger arbitrage, distressed securities, activist investing, and special situations. Hedge fund managers can also use short selling to profit from negative events or outcomes.

Benefits and challenges of hedge fund innovation

Hedge fund innovation can have significant benefits and challenges for both investors and regulators. One of the main benefits of hedge fund innovation is that it can enhance the performance and diversification of hedge fund portfolios. Hedge fund innovation can enable managers to exploit new market opportunities, capture inefficiencies, hedge risks, and adapt to changing market conditions. Hedge fund innovation can also allow investors to access new sources of return, reduce portfolio volatility, and improve their risk-adjusted returns. For example, some studies have found that hedge funds that use innovative strategies, such as activist investing, distressed debt investing, or cryptocurrency trading, tend to outperform their peers and benchmarks (Brav et al., 2008; Agarwal et al., 2016; Bianchi et al., 2019). Another benefit of hedge fund innovation is that it can foster financial innovation and market development. Hedge fund innovation can stimulate the creation and growth of new financial instruments, markets, platforms, and intermediaries. Hedge fund innovation can also enhance the liquidity, efficiency, and competitiveness of financial markets. For instance, some researchers have argued that hedge funds have contributed to the development and diffusion of derivatives markets, electronic trading platforms, prime brokerage services, and securitization markets [11]. Another benefit is that it allows investors to access new sources of return and diversification that are not available in traditional asset classes. Hedge funds can exploit market inefficiencies, arbitrage opportunities, and niche strategies that are often overlooked by other market participants. For example, Glazer (2021) describes how his firm has been investing in SPACs (special purpose acquisition companies) since 2009, a corner of the market that has become very popular in recent years. Hedge fund innovation can also enhance performance by allowing managers to adapt to changing market conditions and investor preferences. For instance, Radke (2021) observes that some hedge funds have shifted their focus from public equities to private investments, which may offer higher returns and lower correlations.

Hedge fund innovation can improve risk management for both hedge funds and their investors. Hedge funds can use innovative techniques and instruments to hedge against various types of risks, such as market, credit, liquidity, operational, and regulatory risks. For example, Reid (2021) notes that hedge funds can use ESG (environmental, social, and governance) factors to identify and mitigate potential risks that may affect their portfolio companies. Hedge fund innovation can also help investors to diversify their portfolios and reduce their exposure to common risk factors. For example, Fludgate (2021) argues that hedge funds can offer diversification benefits by investing in different geographies, sectors, styles, and strategies.

Table 1. Categorization of Hedge Fund Strategies. *Source: Own.*

Strategy Type	Description	Historical Performance
Long-Short Equity	Combines long positions in undervalued stocks with short positions in overvalued stocks.	Historical returns over the past 10 years: 8%
Global Macro	Utilizes global economic and geopolitical trends to make investment decisions.	Historical returns over the past 10 years: 6%
Event-Driven	Focuses on profiting from specific corporate events like mergers, acquisitions, or bankruptcies.	Historical returns over the past 10 years: 9%
Managed Futures	Invests in futures contracts across various asset classes, with an emphasis on trend-following.	Historical returns over the past 10 years: 5%
Distressed Debt	Specializes in investing in the debt of companies facing financial distress or bankruptcy.	Historical returns over the past 10 years: 7%

However, hedge fund innovation also poses significant challenges for investors and regulators, as hedge fund innovation can increase the complexity and opacity of hedge fund activities. Hedge fund innovation can make it difficult for investors to understand, monitor, and evaluate the risks and returns of hedge fund investments. Hedge fund innovation can also make it challenging for regulators to oversee, supervise, and regulate the hedge fund industry. For example, some scholars have highlighted the problems of information asymmetry, moral hazard, adverse selection, and systemic risk that arise from hedge fund innovation (Stulz, 2007; Kambhu et al., 2007; Gennaioli et al., 2013). Another challenge of hedge fund innovation is that it can create new ethical and social issues. Hedge fund innovation can raise questions about the fairness, accountability, responsibility, and sustainability of hedge fund practices. Hedge fund innovation can also have negative externalities on other market participants, stakeholders, and society at large. For example, some critics have accused hedge funds of engaging in unethical or illegal activities, such as insider trading, market manipulation, tax evasion, or environmental degradation (Mallaby, 2010; Young et al., 2013; Cumming et al., 2015). Another challenge is the lack of transparency and standardization in the hedge fund industry, which makes it difficult to monitor and evaluate hedge fund activities and performance. For example, Brav et al. (2018) point out that hedge fund activism can have significant effects on corporate innovation, but these effects are hard to measure and vary across firms and industries. Another challenge is the potential for systemic risk that may arise from hedge fund innovation, especially when it involves leverage, illiquidity, or contagion effects. For example, Fludgate (2021) warns that hedge fund innovation may create new sources of systemic risk that are not well understood or regulated by the authorities.

Classification and performance of hedge fund strategies

These strategies can be broadly categorized into four groups: equity, relative value, event driven, and macro. Each group has different characteristics, risks, and opportunities, and requires different skills and expertise from the fund managers.

- Equity hedge funds invest in stocks, both long and short, based on their relative valuations and expected performance. They may focus on a specific sector, country, or region, or adopt a global perspective. Equity hedge funds aim to exploit market inefficiencies and mispricing, as well as benefit from market trends and movements.

- Relative value hedge funds seek to profit from temporary price differences between related securities, such as stocks, bonds, options, and futures [9]. They use various techniques, such as arbitrage, pairs trading, and convertible bond arbitrage, to capture these price anomalies. Relative value hedge funds tend to have a low correlation with the market and rely on the fund manager's analytical skills and market knowledge.
- Event driven hedge funds invest in securities that are affected by specific events, such as mergers and acquisitions, bankruptcies, restructurings, spin-offs, and litigation. They aim to anticipate the outcome and impact of these events on the securities' prices and take advantage of the resulting opportunities. Event driven hedge funds require extensive research and due diligence, as well as the ability to react quickly to changing situations.
- Macro hedge funds trade in various asset classes, such as currencies, commodities, interest rates, and equity indices, based on their macroeconomic views and analysis. They use leverage and derivatives to amplify their returns and hedge their risks. Macro hedge funds have the potential to generate high returns in volatile markets, but also face significant challenges and uncertainties.

Challenges and opportunities for hedge fund managers and investors

Hedge funds employ a variety of strategies, such as long/short equity, macro, event-driven, relative value, and quantitative, to exploit market inefficiencies and capture alpha. However, hedge funds also face a number of challenges and opportunities in the current market environment, which is characterized by high volatility, low interest rates, rising inflation, geopolitical uncertainty, and changing investor preferences [14]. One of the main challenges for hedge fund managers is to grow their assets under management (AUM) and attract new investors. According to a survey by Ernst & Young, hedge fund managers continue to cite growth as their top priority, although the proportion of respondents who did so in 2014 fell to 57% from 67% in 2013. New growth methods include adding new strategies, identifying new investor bases and increasing penetration with existing investors. However, hedge fund managers also face increased competition from other alternative investment vehicles, such as private equity, venture capital, real estate, and infrastructure funds, which may offer higher returns or lower fees. Another challenge for hedge fund managers is to adapt to the rising fees and an evolving prime broker dynamic. Prime brokers are financial institutions that provide a range of services to hedge funds, such as financing, clearing, custody, reporting, and risk management. However, prime brokers have also increased their fees and tightened their risk limits in response to the regulatory changes and capital requirements imposed after the global financial crisis. This has led some hedge funds to seek alternative sources of financing or diversify their prime broker relationships. Moreover, some hedge funds may face difficulties in accessing certain markets or asset classes that require specialized prime brokers or custodians. Another challenge for hedge fund managers is to incorporate environmental, social, and governance (ESG) factors into their investment process and operations. ESG has become a key topic for investors who are increasingly concerned about the social and environmental impact of their investments. However, ESG is also a complex and subjective concept that may vary across regions, sectors, and stakeholders. Hedge fund managers need to understand the ESG preferences and expectations of their investors and align their policies and practices accordingly. Additionally, hedge fund managers need to measure and report on their ESG performance and impact using standardized frameworks and metrics.

On the other hand, hedge funds also have several opportunities to capitalize on the changing market conditions and investor demands. One of the main opportunities for hedge funds is to exploit the increased volatility and dispersion across markets and sectors. Volatility is a measure of how much the price of an asset fluctuates over time, while dispersion is a measure of how much the returns of different assets diverge from each other. Higher volatility and dispersion create more opportunities for hedge funds to generate alpha by taking advantage of mispricing or arbitrage opportunities. For example, hedge funds can use strategies such as volatility arbitrage, convertible arbitrage, or capital structure arbitrage to profit from the differences in implied or realized volatility or valuation across different securities or instruments. Another opportunity for hedge funds is to invest in private markets or illiquid assets that offer higher returns or yield than public markets or liquid assets. Private markets refer to the markets where securities are not publicly traded or listed on an exchange, such as private equity, private debt, venture capital, or real estate. Illiquid assets refer to the assets that are difficult to sell quickly without affecting their price significantly, such as distressed debt, structured products, or commodities. Private markets or illiquid assets may offer higher returns or yield because they entail higher risk or lower liquidity premiums. For example, hedge funds can invest in special purpose acquisition companies (SPACs), which are shell companies that raise capital through an initial public offering (IPO) and then merge with a private company. Another opportunity for hedge funds is to leverage technology and innovation to enhance their investment

process and operations. Technology and innovation can help hedge funds improve their data collection and analysis, portfolio construction and optimization, risk management and compliance, trading execution and efficiency, and client communication and reporting. For instance, hedge funds can use artificial intelligence (AI), machine learning (ML), natural language processing (NLP), or big data analytics to generate new insights or signals from alternative data sources such as social media, satellite imagery.

Historical data on hedge fund returns and trends of hedge fund strategy evolution.

It is important to understand how hedge fund performance is measured and how hedge fund strategies have changed over time in response to market conditions and investor preferences. One of the common methods for measuring hedge fund performance is the Sharpe ratio, which indicates the excess return per unit of risk (as measured by standard deviation) of a fund over a risk-free rate. A higher Sharpe ratio implies a better risk-reward profile for a fund. However, the Sharpe ratio can be affected by both upside and downside volatility, which may not reflect the true risk preferences of investors. A more refined measure is the Sortino ratio, which only considers downside risk (as measured by the standard deviation of negative returns) in the denominator. A higher Sortino ratio implies a better downside protection for a fund. Another aspect of measuring hedge fund performance is benchmarking, which involves comparing the returns of a fund to a relevant index or peer group. Benchmarking can help investors evaluate the relative performance and skill of a fund manager, as well as the diversification benefits of adding a fund to a portfolio. However, benchmarking hedge funds can be challenging due to the heterogeneity and dynamic nature of hedge fund strategies, as well as the lack of standardized and reliable data sources.

Hedge fund strategies have evolved over time in response to changing market environments and investor demands. For example, after the global financial crisis of 2008-2009, hedge funds faced increased regulatory scrutiny and investor pressure for more transparency and liquidity. As a result, some hedge funds shifted from illiquid and complex strategies to more liquid and simple ones, such as long/short equity or managed futures. Some hedge funds also adopted more flexible fee structures or offered liquid alternatives (such as mutual funds or ETFs) that mimic hedge fund-like strategies. Another trend in hedge fund strategy evolution is the increasing use of quantitative methods and technology. Hedge funds have been adopting more sophisticated data analysis techniques, such as machine learning or natural language processing, to enhance their investment processes and generate alpha. Hedge funds have also been leveraging more alternative data sources, such as social media or satellite imagery, to gain an edge over competitors. Moreover, hedge funds have been exploring new frontiers of investing, such as crypto currencies or ESG factors.

Table 2. Integration of ESG Factors in Hedge Fund Strategies. *Source: Own.*

Fund Name	Integration of ESG Factors	Performance Impact
ESG Hedge Fund A	High integration of ESG criteria into investment decisions.	10% increase in 5-year annualized returns.
Traditional Hedge Fund B	Limited integration of ESG factors.	Performance remained consistent.
ESG-focused ETF C	Passive investment approach with ESG screens.	Slight outperformance of the benchmark index.

A framework for assessing the innovation potential and sustainability of hedge fund strategies

A framework for assessing the innovation potential and sustainability of hedge fund strategies was proposed, based on a literature review of existing research and industry reports. The framework was then applied to some of the emerging and niche strategies in the market, such as cryptocurrency arbitrage, machine learning, ESG investing, and volatility trading. Our framework consists of four dimensions: novelty, complexity, adaptability, and scalability. Novelty refers to the degree to which a strategy introduces new ideas or methods that differ from the conventional or mainstream approaches. Complexity refers to the degree to which a strategy involves sophisticated mathematical models, algorithms, or data sources that are difficult to replicate or understand by others [15]. Adaptability refers to the degree to which a strategy can adjust to changing market conditions

or exploit new opportunities. Scalability refers to the degree to which a strategy can increase its size or scope without compromising its performance or efficiency. We use a scoring system to rate each strategy on each dimension, based on the criteria and indicators derived from the literature. We then aggregate the scores to obtain an overall rating of innovation potential and sustainability for each strategy. We also compare and contrast the strengths and weaknesses of each strategy and discuss the implications for investors and managers.

Key findings are as follows:

- Cryptocurrency arbitrage is a strategy that exploits price differences between different platforms or exchanges that trade cryptocurrencies. It has a high novelty score, as it involves a new asset class that has emerged in recent years. It also has a high complexity score, as it requires advanced technical skills and infrastructure to execute trades quickly and securely. However, it has a low adaptability score, as it depends on the existence and persistence of market inefficiencies that may diminish over time. It also has a low scalability score, as it faces challenges such as liquidity constraints, regulatory uncertainty, and operational risks.
- Machine learning is a strategy that uses artificial intelligence techniques to analyze large amounts of data and generate trading signals or decisions. It has a high novelty score, as it represents a cutting-edge application of technology in finance. It also has a high complexity score, as it involves complex algorithms and models that are often proprietary or black-boxed. However, it has a moderate adaptability score, as it may suffer from overfitting or underperformance when market conditions change, or new data becomes available. It also has a moderate scalability score, as it requires significant computational resources and human expertise to maintain and update.
- ESG investing is a strategy that incorporates environmental, social, and governance factors into investment decisions. It has a moderate novelty score, as it reflects a growing awareness and demand for responsible investing among investors and regulators. It also has a moderate complexity score, as it involves multiple criteria and data sources that may vary across regions or sectors. However, it has a high adaptability score, as it can capture long-term trends and opportunities that may arise from social or environmental changes. It also has a high scalability score, as it can apply to a wide range of asset classes and markets [13].
- Volatility trading is a strategy that bets on the direction or magnitude of price movements in the market. It has a low novelty score, as it is based on well-established concepts and instruments such as options or futures. It also has a low complexity score, as it involves relatively simple calculations or models that are widely available or standardized. However, it has a high adaptability score, as it can profit from various market scenarios or events that cause volatility spikes. It also has a high scalability score, as it can leverage on derivatives or leverage products that offer high exposure with low capital requirements.

Hedge fund managers influence on hedge fund innovation

Hedge fund innovation can be measured by various indicators, such as the number of new funds launched, the diversity of strategies employed, the use of complex instruments or techniques, and the alpha generated by the fund. Hedge fund innovation can also be influenced by the characteristics of hedge fund managers, such as their skills, experience, education, incentives, and preferences.

- Skills: Hedge fund managers need to have certain skills, such as analytical, technical, and interpersonal skills, to identify and exploit market opportunities, design and implement effective strategies, and communicate and negotiate with investors and other stakeholders [16].
- Experience: Hedge fund managers can benefit from their prior experience in different fields, such as finance, academia, or entrepreneurship, to acquire relevant knowledge, networks, and reputation that can facilitate their innovation process
- Education: Hedge fund managers can enhance their human capital and cognitive abilities through formal education, such as degrees or certifications in finance, economics, mathematics, or computer science, which can provide them with theoretical foundations and analytical tools for innovation
- Incentives: Hedge fund managers are motivated by various incentives, such as financial rewards, reputation effects, personal satisfaction, or social impact, which can drive them to pursue innovation goals and overcome challenges and risks
- Preferences: Hedge fund managers have different preferences, such as risk aversion, time horizon, or ethical values, which can shape their innovation decisions and outcomes.

Issues in hedge fund innovation

Hedge funds are often characterized by their flexibility, opacity and heterogeneity, which make them difficult to define and regulate. Hedge funds are also subject to various market forces and incentives that may affect their behavior and performance [16]. Hedge fund innovation raises important regulatory issues and concerns, such as systemic risk, market integrity, investor protection, financial stability, international coordination, market efficiency and investor protection.

- One of the main regulatory challenges posed by hedge funds is the potential for systemic risk, which refers to the risk of widespread disruption or instability in the financial system caused by the failure or distress of one or more financial institutions or markets [17]. Hedge funds may contribute to systemic risk through their direct and indirect exposures to other financial entities, their role in transmitting or amplifying shocks across markets, their involvement in pro-cyclical activities such as herding or fire sales, and their reliance on short-term funding and liquidity [18]. Another regulatory concern is the protection of investors, both in terms of their rights and interests as shareholders of hedge funds, and in terms of their exposure to the risks and returns of hedge fund strategies. Hedge fund investors may face various challenges, such as asymmetric information, agency problems, conflicts of interest, misalignment of incentives, fraud and misconduct. Hedge fund regulation may aim to enhance the transparency, disclosure and governance of hedge funds, as well as to ensure that investors are adequately informed and qualified to invest in such complex and risky products. Another regulatory issue is the impact of hedge funds on market integrity and efficiency, which refers to the fairness, orderliness and functionality of financial markets. Hedge funds may affect market integrity and efficiency through their trading practices and strategies, such as short selling, high-frequency trading, market manipulation or insider trading. Hedge fund regulation may seek to prevent or deter such abusive or disruptive behaviors, as well as to promote market liquidity, competition and innovation [11]. Another regulatory challenge is the coordination and harmonization of hedge fund regulation across different jurisdictions and regions. Hedge funds operate in a global and interconnected environment, which creates opportunities for regulatory arbitrage, fragmentation and inconsistency. Hedge fund regulation may benefit from greater cooperation and convergence among regulators and policymakers, as well as from the adoption of common standards and principles.

Policy recommendations

Based on a systematic review of the literature on hedge fund strategies, this paper aims to provide some policy recommendations for future research in this field. Hedge fund strategies are speculative investment vehicles that exploit superior information held by their managers and use innovative risk management techniques to achieve absolute returns. However, the hedge fund industry is also characterized by a lack of transparency, high leverage, short selling, and potential systemic risks. Therefore, understanding the evolution and innovation of hedge fund strategies is crucial for investors, regulators, and academics. The literature on hedge fund strategies can be classified into four main categories: performance analysis, investment style analysis, correlation analysis and diversification power, and other studies. Performance analysis focuses on the sources and persistence of hedge fund returns, as well as the impact of fees, incentives, and constraints on performance. Investment style analysis examines the classification and identification of hedge fund strategies, as well as the factors that influence their choice and evolution. Correlation analysis and diversification power explore the relationship between hedge fund returns and various asset classes, markets, and risk factors, as well as the benefits of hedge fund allocation for portfolio optimization. Other studies cover a wide range of topics, such as hedge fund regulation, governance, activism, liquidity, risk management, and social responsibility.

Based on the review of these categories, the following policy recommendations for future research was suggested:

- Develop more robust and dynamic models to capture the nonlinearities, asymmetries, and time-varying features of hedge fund returns and risk exposures.
- Incorporate alternative data sources and methods, such as textual analysis, machine learning, and network analysis, to enhance the identification and classification of hedge fund strategies and their evolution over time.
- Investigate the impact of hedge fund innovation on market efficiency, stability, and liquidity, as well as the spillover effects across different markets and regions.
- Assess the implications of hedge fund regulation and disclosure for investor protection, market discipline, and systemic risk mitigation.
- Explore the ethical and social dimensions of hedge fund strategies, such as their environmental, social,

and governance (ESG) practices, their role in corporate governance and activism, and their contribution to social welfare and inequality.

Suggestions for further study

This study has provided a systematic review of the literature on the evolution and innovation of hedge fund strategies and proposed a framework for future research based on the gaps and limitations identified. However, this study is not without its own limitations and avenues for further research. Some of the possible directions for future research are:

- To empirically test the proposed framework using a large and representative sample of hedge funds across different time periods and market conditions, and to compare the results with existing classifications and typologies of hedge fund strategies.
- To examine the performance implications of hedge fund strategy innovation and evolution, such as how different types of innovations affect the risk-return profile, persistence, diversification benefits, and market impact of hedge funds.
- To investigate the diffusion and adoption of hedge fund strategy innovations across the industry, such as how quickly and widely new strategies are adopted by other hedge funds, and what factors influence the diffusion process.
- To analyze the spillover effects and externalities of hedge fund strategy innovation and evolution on other market participants, such as how new strategies affect the pricing efficiency, liquidity, volatility, and systemic risk of various asset classes and markets.

Impact

The article, "Evolution and Innovation of Hedge Fund Strategies: A Systematic Review of literature and a Framework for Future Research," has profound implications for academia, practice, and policy. This systematic review comprehensively explores the historical evolution and contemporary trends within hedge fund strategies, serving as a foundational resource for scholars and researchers. It not only consolidates existing knowledge but also highlights critical research gaps, providing a structured framework for future investigations. This framework is a valuable guide for shaping the future academic agenda and promoting innovation within the hedge fund industry. Moreover, the article offers practical insights for hedge fund professionals, allowing them to adapt to industry shifts, and it informs policymakers in shaping effective regulations. Furthermore, by enhancing investor awareness, it empowers individuals to make more informed investment decisions. In summary, this research contributes to knowledge enrichment, informs practice, influences policy, and enhances financial literacy. With its comprehensive review and future research framework, it stands as a unifying reference point that can guide meaningful discussions and foster consensus on the intricacies of hedge fund strategies, thereby serving as a common ground capable of ending any argument.

Conclusion

This study provides a systematic review of the literature on the evolution and innovation of hedge fund strategies. The main objective is to identify the key drivers, challenges and opportunities for hedge fund managers and investors in a rapidly changing and competitive industry. The study adopts a multidisciplinary approach that covers various aspects of hedge fund strategies, such as performance, risk, regulation, governance, innovation and diversification. The study also proposes a conceptual framework for future research that integrates different perspectives and dimensions of hedge fund strategies.

The main findings of the literature review are as follows:

- Hedge fund strategies have evolved over time in response to market conditions, investor preferences, regulatory changes and technological developments. Hedge funds have diversified their sources of returns, increased their use of leverage and derivatives, adopted more dynamic and complex trading strategies, and explored new markets and asset classes.
- Hedge fund performance is influenced by various factors, such as market exposure, manager skill, fund size, fees, liquidity, leverage, style drift and survivorship bias. Hedge funds have shown some ability to generate positive risk-adjusted returns over the long term, but also exhibit significant heterogeneity and variability across different strategies, periods and market regimes.
- Hedge fund risk management is a critical aspect of hedge fund strategies, as hedge funds face various types of risks, such as market risk, liquidity risk, operational risk, counterparty risk, regulatory risk and reputational risk. Hedge funds employ various risk management techniques, such as hedging, diversification, stress testing, scenario analysis and value-at-risk. However, hedge fund risk

management also poses some challenges, such as data availability and quality, model uncertainty and validation, and alignment of incentives between managers and investors.

- Hedge fund regulation has increased in the aftermath of the global financial crisis, as hedge funds have been perceived as potential sources of systemic risk and market instability. Hedge fund regulation aims to enhance transparency, disclosure, oversight and supervision of hedge funds and their activities. However, hedge fund regulation also has some drawbacks, such as regulatory arbitrage, compliance costs and unintended consequences for hedge fund strategies and performance.
- Hedge fund governance refers to the mechanisms and processes that ensure the accountability and alignment of interests between hedge fund managers and investors. Hedge fund governance involves various actors and instruments, such as boards of directors, auditors, administrators, prime brokers, custodians, lawyers, consultants and contracts. Hedge fund governance affects various aspects of hedge fund strategies, such as fees, liquidity terms, redemption rights and investment restrictions.
- Hedge fund innovation is the process of creating new or improved hedge fund products or services that meet the needs or expectations of hedge fund managers or investors. Hedge fund innovation can be driven by various factors, such as competition, regulation, technology or demand. Hedge fund innovation can take various forms, such as new strategies, new instruments, new markets or new structures.
- Hedge fund diversification is the process of allocating capital across different hedge fund strategies or sub-strategies that have low or negative correlation with each other or with traditional asset classes. Hedge fund diversification can enhance portfolio performance by reducing volatility and downside risk.

Competing interest statement

In regard to the research writing, and publication of this article, the authors affirm that they do not have any competing interests. The design, implementation, analysis, interpretation, and reporting of the results were all done independently from the funding sources. When conducting research involving human subjects and data, the authors followed all applicable ethical principles and standards. Likewise, the study includes all necessary data. In addition to this, all authors made intellectual contributions towards this research.

Conflict of interest

There are no conflicts to declare.

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References

[1] G. Connor, T. Lasarte, An Introduction to Hedge Funds Strategies. Introductory Guide, Bus. Econ. (2004) 1–16. http://eprints.lse.ac.uk/24675/1/dp477.pdf.

[2] N. Zahoor, Z. Khan, J. Wu, S.Y. Tarba, F. Donbesuur, H. Khan, Vertical alliances and innovation: A systematic review of the literature and a future research agenda, Technovation. 122 (2023) 102588. https://doi.org/10.1016/j.technovation.2022.102588.

[3] A.S. Troshin, S. V. Kupriyanov, I.S. Sandu, Investment and Innovative Component of Strategic Development of the Region (on the Example of the Belgorod Region), IOP Conf. Ser. Earth Environ. Sci. 272 (2019) 032236. https://doi.org/10.1088/1755-1315/272/3/032236.

[4] J.-F. Bacmann, P. Jeanneret, S. Scholz, What correlation does not tell you about hedge funds: A factor approach to hedge fund correlations, J. Deriv. Hedge Funds. 14 (2008) 90–101. https://doi.org/10.1057/jdhf.2008.10.

[5] M.M. Keupp, M. Palmié, O. Gassmann, The Strategic Management of Innovation: A Systematic Review and Paths for Future Research, Int. J. Manag. Rev. 14 (2012) 367–390. https://doi.org/10.1111/j.1468-2370.2011.00321.x.

[6] H. Sun, Y. Wan, L. Zhang, Z. Zhou, Evolutionary game of the green investment in a two-echelon supply chain under a government subsidy mechanism, J. Clean. Prod. 235 (2019) 1315–1326. https://doi.org/10.1016/j.jclepro.2019.06.329.

[7] F.S. Lhabitant, M. Learned, Hedge Fund Diversification: How Much is Enough?, SSRN Electron. J. (2005). https://doi.org/10.2139/ssrn.322400.

[8] D. Norris, M. Ciesielska, Towards a framework for innovation orientation within business and

management studies: A systematic review and paths for future research, J. Organ. Chang. Manag. 32 (2019) 123–144. https://doi.org/10.1108/JOCM-02-2018-0051.

[9] M. Christofi, H. Khan, L. Iaia, Responsible innovation in Asia: A systematic review and an agenda for future research, Asia Pacific J. Manag. (2022). https://doi.org/10.1007/s10490-022-09839-4.

[10] W. Fung, D.A. Hsieh, A primer on hedge funds, J. Empir. Financ. 6 (1999) 309–331. https://doi.org/10.1016/S0927-5398(99)00006-7.

[11] N.Y. Naik, T. Ramadorai, M. Stromqvist, Capacity constraints and hedge fund strategy returns, Eur. Financ. Manag. 13 (2007) 239–256. https://doi.org/10.1111/j.1468-036X.2006.00353.x.

[12] M. Palmié, J. Wincent, V. Parida, U. Caglar, The evolution of the financial technology ecosystem: An introduction and agenda for future research on disruptive innovations in ecosystems, Technol. Forecast. Soc. Change. 151 (2020) 119779. https://doi.org/10.1016/j.techfore.2019.119779.

[13] O.S. Sabirov, Improving Ways to Increase the Attitude of the Investment Environment, Rev. Gestão Inovação e Tecnol. 11 (2021) 1961–1975. https://doi.org/10.47059/revistageintec.v11i2.1811.

[14] F.T. Magiera, Measuring Risk in the Hedge Fund Sector, CFA Dig. 38 (2008) 96–96. https://doi.org/10.2469/dig.v38.n1.45.

[15] F. He, X. Miao, C.W.Y. Wong, S. Lee, Contemporary corporate eco-innovation research: A systematic review, J. Clean. Prod. 174 (2018) 502–526. https://doi.org/10.1016/j.jclepro.2017.10.314.

[16] M.M. Crossan, M. Apaydin, A multi-dimensional framework of organizational innovation: A systematic review of the literature, J. Manag. Stud. 47 (2010) 1154–1191. https://doi.org/10.1111/j.1467-6486.2009.00880.x.

[17] D.P.J. Capocci, A.H.R.F. Corhay, G. Hubner, Hedge Fund Performance and Persistence in Bull and Bear Markets, SSRN Electron. J. (2011). https://doi.org/10.2139/ssrn.483222.

[18] F. Polzin, Mobilizing private finance for low-carbon innovation – A systematic review of barriers and solutions, Renew. Sustain. Energy Rev. 77 (2017) 525–535. https://doi.org/10.1016/j.rser.2017.04.007.

EFFECTS OF FRUIT BAGGINGS AS PREHARVEST TREATMENTS ON THE FRUIT QUALITY OF PINEAPPLE 'MD-2'

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Higlight
Preharvest method of bagging and enhancement of pineapple fruit quality.

Abstract
The demand for fresh pineapple fruit is currently highest for the MD2 pineapple variety. Continuous efforts are made to enhance the quality of MD2 pineapples, including the fruit skin color, flesh color, sweetness, and minimizing sunburn damage. Bagging is one of the pre-harvest methods that can be employed for this purpose. This research aims to find suitable bagging materials that meet the industry's criteria and assess the severity of sunburn in each bagging treatment. A completely randomized design was used in this study, with six different bagging materials and pineapples aged 80 Days After Forcing (DAF). The bagging materials used were the control, blue Polyethylene (PE) bag, white PE bag, black paranet bag, paper bag, and the existing cap-shaped bagging technique using recycled paper from banana bagging, as utilized by PT. Great Giant Pineapple. Each treatment involved 120 pineapple samples harvested at 140 DAF. MD2 pineapples without bagging were found to provide the best results according to PT. Great Giant Pineapple's criteria, with green skin color (1.35%) and uniform yellow flesh (85.62%).

Keywords
Pineapple; bagging; polyethylene; paper; black shade net.

Introduction

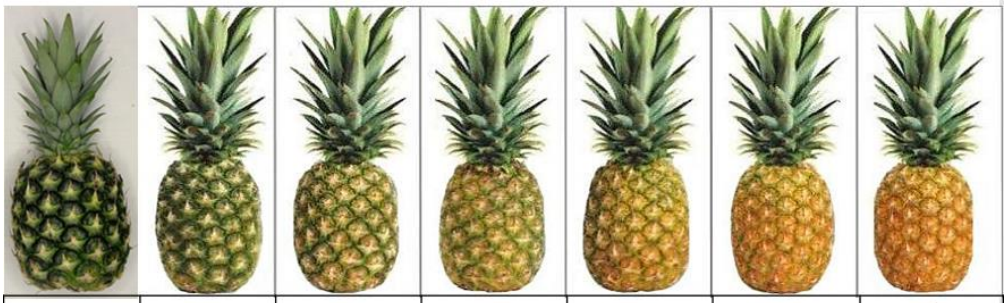
Pineapple (Ananas comosus L. Merr.) is a leading fruit commodity with the highest export volume in Indonesia. Exported pineapples are typically harvested to meet consumer demand. To obtain perfectly ripe pineapples, farmers usually manually select them. The harvest maturity index is based on the degree of skin color development [1]. The widely traded cultivar for fresh fruit is the MD2 pineapple cultivar. The MD2 pineapple cultivar is the most popular globally, accounting for 50%-55% of the world market, mainly due to its excellent taste, sweetness, appealing golden flesh, golden skin color, maturity, and perfect cylindrical shape. MD2 pineapples are more resistant to internal browning but are vulnerable to fruitlet core rot and more sensitive to Phytophthora than Smooth Cayenne [2]. Some challenges in pineapple cultivation include a decrease in fruit quality and aesthetic value due to injuries such as sunburn, mechanical damage during transportation from the field to the factory and packing facilities, and during storage. This happens because MD2 pineapples have thin and less dense physical characteristics [3].

Several protective measures against sun exposure include shading [4], the application of liquid sunshield films [5], plant protection application [6], and fruit bagging [7–10]. Compared to shading nets and the application of liquid sunshield films and plant protectants, fruit bagging has many advantages due to its relatively low cost and fewer negative effects. This not only protects the fruits but also influences fruit growth and quality, as is commonly used in other fruits [11,12]. Bagging treatment is done during the fruit growth stage with the aim

of protecting the fruit from pathogen and insect attacks, as well as improving the fruit's appearance and physicochemical properties [13]. The use of bagging materials has been proven to reduce sunburn rates in some fruit commodities [11]. The fresh pineapple marketing industry, such as PT. Great Giant Pineapple, continues to improve the quality of pineapples to meet market demands. The desired industry appearance criteria are MD2 pineapples with green outer skin and uniformly yellow flesh. This research aims to find suitable bagging materials that meet these industry criteria.

Methods

The research was conducted at the Research and Development Postharvest Laboratory of PT. Great Giant Pineapple (PG4), located at Jl. Taman Nasional Way Kambas Raja Basa Lama I, Labuhan Ratu District, East Lampung, Indonesia. The study was conducted over a period of 70 days before pineapple fruit harvest, from September to November 2022, in area 406Q1. Observations were made on the 1st day after treatment and at the time of harvest. This research utilized a Completely Randomized Design with 6 treatments (bagging materials) and five replications, with four fruit samples in each observation for each treatment. Each treatment involved 120 pineapple fruit samples harvested at 140 DAF (Days After Forcing). The bagging materials consisted of blue Polyethylene (PE) bags, white PE bags, black paranet bags, paper bags, and existing cap-shaped bagging techniques using recycled paper from banana bagging, as used by PT. Great Giant Pineapple. Observations were made on the skin color presentation, flesh color, and soluble solids content using an Atago hand refractometer. Observations of external pineapple fruit ripeness were conducted qualitatively by assessing the percentage of yellow color on the pineapple skin surface according to the guidelines for determining the percentage of shell color in Figure 1.



0	1	2	3	4	5	6
0%	> 0 – 10%	>10 – 20%	> 20 – 35%	>35 – 50%	> 50 – 75%	>75 –100%

Figure 1. Guidelines for determining the percentage of shell color in MD2 pineapples. *Source: PT. Great Giant Pineapple*.

The observation of flesh color was also carried out qualitatively. Observations were conducted by cutting the pineapple fruit into two vertical halves and then measuring the flesh color using a ruler from the bottom to the top of the fruit. Measurement was done by comparing the length of the yellow color with the length of the pineapple fruit, which is the length of the yellow-colored part of the pineapple fruit divided by the length of the pineapple fruit, multiplied by 100%. Data were processed by comparing the means with a 95% confidence interval (α=0.05) for each treatment group and post hoc tested using the Tukey test. The data table is presented along with letter notations to indicate their significance. Statistical data were processed using the Minitab 19 program.

Results and discussion

The occurrence of sunburn is a complex process, closely related to climate, varieties, fruit development stage, tree vitality, fruit growth position, and soil conditions [14]. In this study, the bagging treatment on pineapple fruits did not significantly impact the percentage of sunburn as observed in this research. No instances of sunburn were found in any of the bagging treatment samples, as presented in Table 1.

These results are attributed to the fact that the planting was conducted during the wet season with low environmental temperatures and high rainfall, as shown in Figure 1.

The determination of the wet season is based on the statement from the Ministry of Agriculture of the Republic of Indonesia, which indicates that the suitable rainfall for pineapple cultivation in Indonesia ranges from 1200-4000 mm per year or 3-10 mm per day, depending on the location and the pineapple varieties being cultivated.

During the period of this study, the recorded rainfall could reach up to 52.80 mm in a single day. With high rainfall, air humidity also increases, with the highest humidity reaching 94.13%, and the lowest at 71.01%. Pineapples prefer a humidity of 70% for their growth [13]. The environmental temperatures during September to November 2022 ranged from a maximum of 28.40°C to a minimum of 24.71°C, with an average of 26.72°C. These temperatures fall within the normal range for pineapple growth, which typically ranges from 22-32°C [14]. Sunburn commonly occurs during the summer with temperatures exceeding 32°C [15]. In well-lit environments during the day, the irradiance reaching the Earth's surface is 1,000 W/m² [6], whereas in this study, the highest solar radiation reached only 220.53 W/m².

From the temperature measurements of MD2 pineapple fruit's surface in the morning, noon, and afternoon, there were no significant temperature differences among the treatments. However, the bagging treatment per treatment provided significant temperature values, as shown in Table 2.

Table 1. The Influence of Different Bagging Treatments on Sunburn Incidence in MD2 Pineapples. *Source: Own.*

Treatment	**Sunburn (%)**
No bagging	0
Blue PE bag	0
White PE bag	0
Black shade net	0
Paper bag	0
Bagging existing	0

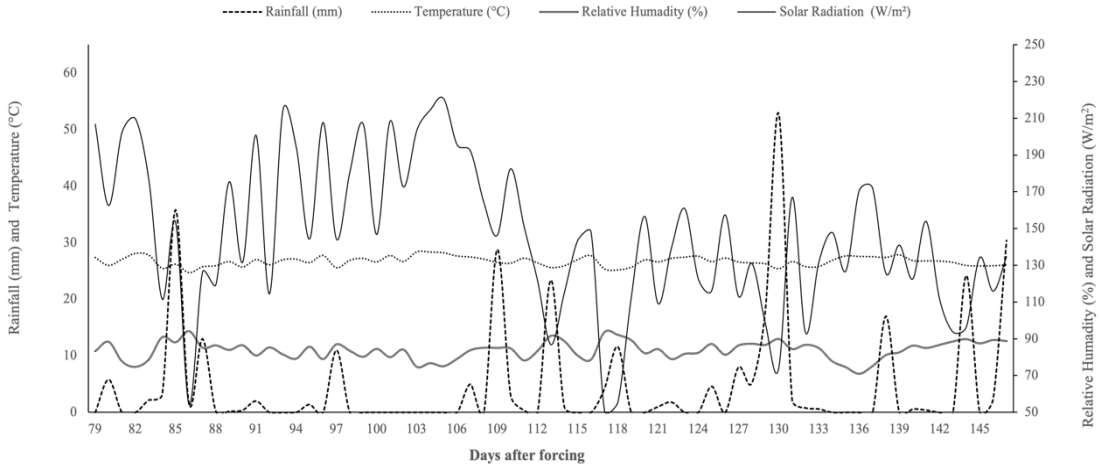


Figure 1. Weather data accumulated based on the Automatic Weather Station (AWS). Source: Own.

Table 2. The lowest temperature was recorded for the unbagged fruit, which was 30.57°C in the morning, 32.80°C at noon, and 33.3°C in the afternoon. *Source: Own.*

Treatment	**Shell temperature (°C)**			**Bagging Temperature (°C)**		
	9:00 AM	12:00 PM	03:00 PM	9:00 AM	12:00 PM	03:00 PM
No bagging	29,08 a	35,09 a	33,77 a	30,57 c	32,80 d	33,33 c
Blue PE bag	28,64 a	35,11 a	33,63 a	32,43 b	33,0 cd	35,33 bc
White PE bag	28,38 a	34,97 a	33,73 a	33,40 a	33,2 c	37,23 b
Black shade net	28,39 a	34,62 a	33,42 a	33,70 a	33,8 b	39,60 a
Paper bag	28,23 a	34,52 a	33,42 a	33,80 a	34,2 a	39,63 a
Bagging existing	28,24 a	34,33 a	33,43 a	33,90 a	34,3 a	39,70 a

[1]Lowercase letters indicate statistically significant differences by Tukey (p≤0.05).

The fruit temperature can increase due to direct sunlight exposure, and the exposed part of the fruit can exceed 50°C if the environmental temperature approaches 30°C [16]. In this experiment, the pineapple fruit's skin did not reach those temperatures because it had a lower environmental temperature than previously recommended

(average of 26.72°C). This statement supports the absence of sunburn in this study due to the lower environmental temperature. Bagging leads to microclimatic changes around the fruit [17], and in this study, the use of bagging was able to increase the bagging temperature. The air temperature inside the bag will be higher, up to 5 degrees higher on bright summer days [18].

Bagging fruit affects the external ripeness level of pineapple fruit (shell color). The highest shell color was obtained in the blue PE bag treatment, at 9.20% of yellow pineapple skin, and the lowest was found in unbagged fruit, at 1.35% of yellow pineapple skin. Bagging did not affect the flesh color of pineapple fruit, as all bagging treatments showed statistically insignificant results, as presented in Table 3.

Table 3. The effect of bagging material treatments onthe skin color (shell color) and flesh color of MD2 pineapple clones(%). *Source: Own.*

Treatment	Shell color (%)	Flesh color (%)
No bagging	1,35 b	85,62 a
Blue PE bag	9,20 a	88,63 a
White PE bag	4,75 ab	75,51 a
Black shade net	4,00 ab	81,77 a
Paper bag	7,55 ab	80,75 a
Bagging existing	2,15 ab	86,45 a

[1]Lowercase letters indicate statistically significant differences by Tukey (p≤0.05).

Bagging can enhance the color of the fruit skin [19]. In this study, the blue PE bag had a more yellow skin color compared to other bagging materials. This is because the blue wavelength can transmit the appropriate energy to the fruit, resulting in a more evenly bright fruit color. This is in line with the research by [20], which concluded that the blue wavelength (around 440-480 nm) is important for photosynthesis in cultivated plants.

Impact

The harvesting of MD2 pineapples is based on their external ripeness level. Pineapples that were bagged before harvesting showed a significantly higher external ripeness level compared to unbagged pineapples. This indicates that the use of bagging can accelerate the shelf life of pineapple fruit. The industry desires pineapples with a long shelf life for sale. Therefore, using bagging during the rainy season can be economically detrimental to the industry.

Conclusions

No instances of sunburn were found in any of the bagging treatments. This is because the planting was conducted during the rainy season. Unbagged pineapples had green skin with uniformly yellow flesh, which aligns with the preferences of PT. Great Giant Pineapple. Consequently, during the rainy season, there is no need to use bagging for pineapple cultivation.

Conflict of interest

There are no conflicts to declare.

Acknowledgments

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References

[1] M.T. Soedibyo, The effect of picking age for subang pineapple fruit on quality, Hortikultura. 2 (1992) 36–42.

[2] D.P. Bartholomew, E. Malézieux, G.M. Sanewski, E. Sinclair, Inflorescence and fruit development and yield., in: Pineapple Bot. Prod. Uses, CABI Publishing, UK, 2003: pp. 167–202. https://doi.org/10.1079/9780851995038.0167.

[3] A.N. Shafawi, A. Azmi, Z. Zain, S. Ab Azid, F.M. Abu, S.N. Nasarudin, R. Mustaffa, L.C. Ying, N. Isahak, R. Khairulfuaad, Reducing sunburn incidence in MD2 pineapple Uusing mechanical preharvest treatment to overcome post-harvest losses in Malaysia, Int. J. Agric. For. Plant. 10 (2020).

[4] K. Kishore, R. Mishra, N.P. Singh, G.M. Lal, Influence of shade intensity on growth, biomass allocation, yield and quality of pineapple in mango based intercropping system, Sci. Hortic. (Amsterdam). (2021).

[5] E.C. Rabie, B.W. Mbatha, Evaluation of the efficacy of eclipse ® in reducing sunburn in 'Queen' pineapple of South Africa, Acta Hortic. (2016) 241–248. https://doi.org/10.17660/ActaHortic.2016.1111.35.

[6] D. Bell, R. Ortiz V., C. Scott, N. Phillips, Surround® crop protectant - for thereduction of sunburn damage and heat stress in pineapple, Acta Hortic. (2006) 179–184. https://doi.org/10.17660/ActaHortic.2006.702.23.

[7] L. XinHua, et al., Effects of bagging onfruit growth and quality of pineapple in different periods, Chinese J. Trop. Crop. 31 (2010).

[8] L. XinHua, S. DeQuan, QuingSongW., L. ShenHui, Z. XiuMei, GuangMingS., Effects of bagging with different paper bags onfruit growth and quality of pineapple, J. Trop. Crop. 28 (2011).

[9] S. Prabha, K. Kumari, P. Deb, Effect of Fruit Bagging on Physico-Chemical Properties of Pineapple CV Mauritius, Int. J. Curr. Microbiol. Appl. Sci. (2018).

[10] W.F. Zhao, Y.F. Peng, H.Y. Chen, X.C. Zhang, Q.S. Wang, Effects of different bagging time and bag materials on yield and quality of pineapple, Guangdong Agric. Sci. 46 (2019) 27–33.

[11] R.R. Sharma, S.V.R. Reddy, M.J. Jhalegar, Pre-harvest fruit bagging: a useful approach for plant protection and improved post-harvest fruit quality – a review, J. Hortic. Sci. Biotechnol. 89 (2014) 101–113. https://doi.org/10.1080/14620316.2014.11513055.

[12] N.M.D. Buthelezi, T.P. Mafeo, N. Mathaba, Preharvest bagging as an alternative technique for enhancing fruit Quality: A review, Horttechnology. 31 (2021) 4–13. https://doi.org/10.21273/HORTTECH04658-20.

[13] M.M. Ali, R. Anwar, A.F. Yousef, B. Li, A. Luvisi, L. De Bellis, A. Aprile, F. Chen, Influence of bagging on the development and quality of fruits, Plants. 10 (2021) 358. https://doi.org/10.3390/plants10020358.

[14] Z. Weifeng, Y. Weixiu, M. Zhiling, Z. Xiaoyan, C. Liguo, L. Shenghui, Z. Yanfang, Effects of time and height of shading on yield and quality of pineapple, IOP Conf. Ser. Earth Environ. Sci. 512 (2020) 012101. https://doi.org/10.1088/1755-1315/512/1/012101.

[15] J. Dhungel, S.P. Bhattarai, D.J. Midmore, Aerated water irrigation (oxygation) benefits to pineapple yield, water use efficiency and crop health, Adv. Hortic. Sci. 26 (2012) 3–16.

[16] Z.S. F. Ardianto, Y. R., B. Alfaresi, Intensity of sunlight on solar panels to the power produced, (2021).

[17] G.M. Bartholomew, D.P. Sanewski, Inflorescence and fruit development and yield, in: Pineapple Bot. Prod. Uses, 2018: pp. 223–268.

[18] C. Amarante, N.H. Banks, S. Max, Preharvest bagging improves packout and fruit quality of pears (Pyrus communis), New Zeal. J. Crop Hortic. Sci. 30 (2002) 93–98. https://doi.org/10.1080/01140671.2002.9514203.

[19] L. Wang, X. Zhang, Y. Liu, X. Shi, Y. Wang, C. Zhang, Z. Zhao, The effect of fruit bagging on the color, phenolic compounds and expression of the anthocyanin biosynthetic and regulatory genes on the 'Granny Smith' apples, Eur. Food Res. Technol. 237 (2013) 875–885. https://doi.org/10.1007/s00217-013-2055-1.

[20] K.J. McCree, The action spectrum, absorptance and quantum yield of photosynthesis in crop plants, Agric. Meteorol. 9 (1972) 191–216.

ENERGY, ECONOMIC AND ENVIRONMENTAL FEASIBILITY OF ENERGY RECOVERY FROM WASTEWATER TREATMENT PLANTS IN MOUNTAINOUS AREAS: A CASE STUDY OF GHARYAN CITY – LIBYA

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Abstract
Wastewater treatment facilities at high places can give chances for renewable and sustainable energy generation by putting hydroelectric turbines at the input and drain channels of wastewater treatment plants, and they can also use the sludge generated during the treatment process to make biogas, which can be used to generate power. Purified water is subsequently used to irrigate decorative plants along highways, in gardens, and in woods. The fermentation wastes are utilized as organic fertilizer to improve agricultural soil quality. At the Gharyan sewage station, a hybrid system consisting of a hydroelectric station and an electric generator powered by biogas is proposed in this research. This is because the city is distinguished by its high location, which is approximately 713 m above sea level. The results showed that the proposed system would provide an electric power of 490 kW, which is sufficient to cover 87.5% of the electrical energy consumption of the station. The amount of treated water is approximately 13,000 m^3/day, and the amount of organic fertilizer is about

17 tons/day. The investment value is anticipated to be around $1,478,000, while the cost of producing a unit of electric energy is expected to be 2.83 ¢/kWh. This system's yearly net profit is predicted to be $307,765. The capital's recovery period is anticipated to be 3.44 years. The planned hybrid system will limit the discharge of an estimated 1,886 tons of CO_2 gas each year.

Keywords
Biomass Energy; Gharyan; hydroelectric power; Libya; potential energy; sewage treatment plants.

Introduction

Energy is one of the most important aspects of human existence owing to its relevance in infrastructural development and as a driving force in economic development and employment creation. Energy-related concerns took a new turn near the end of the past century, particularly those linked to the generation of electric power from fossil fuels and the advent of major environmental difficulties that endanger human existence on Earth, such as climate change and global warming. Burning fossil fuels generates more than 64% of the world's power and thermal energy (Figure 1a). In Libya, almost 99% of power is generated using fossil fuels (Figure 1b), putting the energy industry ahead of all other human activities in terms of emissions, accounting for around 36% of the country's carbon dioxide emissions [1,2]. Figure 1 depicts the contribution of primary energy utilized in power generation in the globe and Libya in 2020. At the same time, there is a huge growth in global electricity demand. These issues are continually rising, indicating the need for alternative energy sources that are high in efficiency, ecologically benign, and sustainable [3,4]. One of these options is to create electricity as near to the point of consumption as feasible, utilizing locally accessible renewable and clean energy sources such wind energy [5–8], solar energy [9–13], biomass energy [8,14–17], hydropower [18–21].

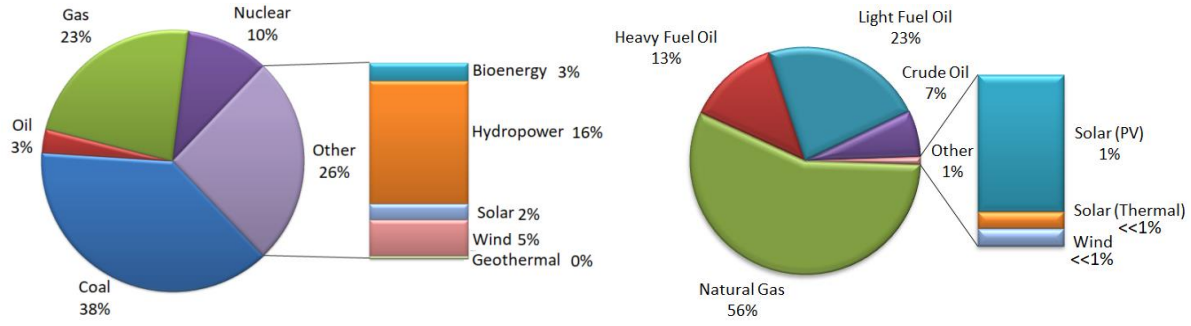

Figure 1. Contribution of fuel type to electrical power generation. *Source: Own.*

In order to satisfy the Libyan government's obligations to the international community to lower CO_2 emission rates on the one hand, and to provide its society with a safe and sustainable source of energy on the other, the Libyan government unveiled its strategic plan to produce electric power from some of the renewable energies accessible in the country over the next thirty years during COP 27 (The Conference of Nations United Climate Change), which was held in Sharm El-Sheikh, Egypt, from June 6 to June 8, 2010. The strategic plan seeks to increase renewable energy participation in combined electric energy production by 25% by 2025, up to 30% by 2030, and over 60% by 2050 through photovoltaic and thermal generation of solar energy and wind energy [22]. Although hydroelectric energy and biomass energy are not included in the plan, their use is an absolute requirement as a source of energy generation, as is the case with mountainous water treatment facilities, or as a source of biofuel to run electricity generating generators or gas turbines, or to store energy in hydraulic energy tanks (Hydropower Storage) and integration with the sources stated in the plan [23,24]. Hydroelectric energy is also regarded one of the cleanest renewable energies, with a CO_2 emission ratio of roughly 18.5 kg CO_2/kWh over the station's life cycle [25]. Sewer water is a renewable and sustainable energy source, where electrical power may be created by putting turbines inside city sewage pipelines and utilizing regular gravity flow [26]. For example, the Australian government's New South Wales government built its first plant in 2010, with a capacity of 4.5 MW, utilizing treated wastewater falling from 60 m to produce 58% of its power [27]. Rosa et al. offered a list of 49 wastewater hydropower plants from across the world. Two Swiss facilities are harnessing the energy potential of higher elevations. The Profray station (capacity 8,600 m^3/day) in Bagnes generates hydroelectric electricity (851 MWh/year, equivalent to a 380-kW generator) from sewage flow from a height of 449 m. The La Louve station, which also generates in Lausanne (with a capacity of 10,400 m^3), transfers

almost half of the energy (460 MWh/year, equal to a 170 kW generator) from the water dump to the station at an altitude of 180 m [28]. The capacity of the water treatment facility in the Austrian city of Seefeld Zirl is 1,192 kW from a height of 94 m [29].

With a capacity of 364,000 m^3/day, Jordan's Samara facility near Amman processes over 70% of the country's wastewater. Internal energy resources meet approximately 80% of the plant's energy requirements. The treated water is also utilized in agriculture, accounting for around 10% of Jordan's total water usage. The facility also avoided the emission of 300,000 tons of CO_2/year into the atmosphere by producing energy [30]. In Turkey, Baran discovered seven prospective geographic areas that might generate 38.53 GWh/year of energy from a hydroelectric wastewater treatment plant, which would be adequate to provide street lights in these seven areas [31]. According to a study of prior studies, wastewater treatment facilities can profit from generating electrical energy to meet a portion of the station's electrical energy requirements, in addition to purifying the water before expelling it into the environment. This is accomplished in numerous ways:

- Making use of the treatment plant's potential energy in high mountain cities.
- Using kinetic energy of wastewater owing to gravity in the sewage network.

Despite its relevance, the topic has gotten little attention at the municipal level. Many studies dealt with the subject of hydroelectric energy from the standpoint of storing energy in high reservoirs or river energy, but only one study dealt with the question of utilizing wastewater to create electric power in Libya [17]. The remainder of the paper is divided into the following sections: Section Two (Materials and Work Methods), which provides a description of the existing site of the sewage plant as well as theoretical energy, economic, and environmental calculations. Section 3 (results and comments) gave the outcomes. Section 4 examines the overall state of wastewater treatment plants in Libya. Section 5 contains the conclusions and suggestions.

Materials and Work Methods

General data of the study site

- Gharyan is located on the Western Mountain in Libya's northwestern region. Gharyan is located around 713 meters above sea level (Figure 2). According to 2021 figures, its population is around 187,854 people, and its area without suburbs is 4,660 m^2 [32]. The wastewater collection and treatment facility, which has a capacity of 2,220 m^3 and handles an estimated 13,000 m^3/day, was built in 1971. It solely serves the Taghsat region, which has a population of around 19,000 people according to 2021 figures, with an average per capita of approximately 0.684 m^3/day. Figure 3 depicts an aerial photograph of the station. The sewage treatment plant is 673 m above sea level. At this height, the potential energy is approximately 6.6 MW/m^3. On June 7, 2019, the writers of this article went to the sewage plant to learn about the facility's components and to acquire design and operating information. Although there is no information accessible on the population's sewage water rates in Libya, the municipality of Gharyan is undertaking research on linking the entire city to a sewage network, as well as creating a new sewage collecting station to replace the present one, which has expired. This offered the present research a design component by emphasizing the prospect of generating electrical energy from the new station and taking this benefit into account while contracting to create the new station. The treatment plant works in phases, which are as follows: Station entrance: The station has two entrances, each with a crusher for breaking up solid materials.
- Sand lifter: a basin with a motor that circulates the water and a pump that returns it to the basin. A scraper is used to clear the sand that has accumulated at the basin's bottom.
- Aeration basins: There are two aeration basins at the station, where air blowers activate microorganisms inside the basins to analyze organic materials and eradicate pathogens.
- Sedimentation basins: they are used to settle organic debris (sludge) within ponds.
- Filters: they remove plankton from the water.
- Chlorine tank: A chlorine tank into which chlorine is fed from chlorine cylinders via a mechanism.
- Return pump: screw pumps that return water from all stages of the station and transport sludge from sedimentation basins to drying basins or return water to aeration basins.
- Drying basins: These are used to dry organic products.

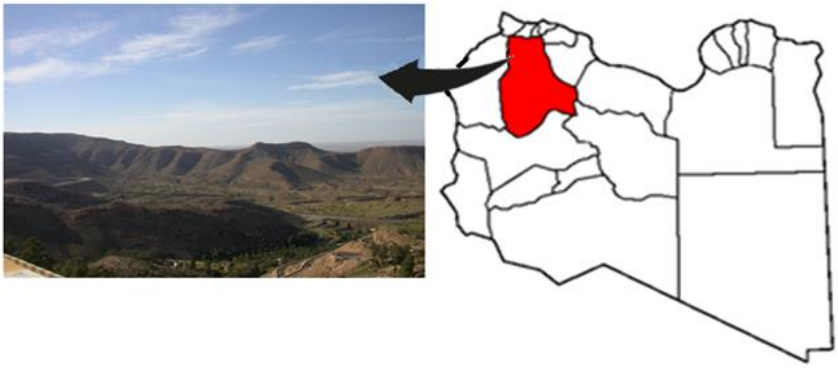

Figure 2. Map of Libya showing the location of the city of Gharyan and a picture of the terrain of the region. *Source: Own.*

Figure 3. An aerial photo of the wastewater treatment plant in Gharyan city.
Source: https://earth.google.com/web/search/32.15153203,13.03476738,662.53720067a

Design and operational data for the wastewater treatment plant in Gharyan city

The station receives wastewater from the city's sewage network via two 0.9-meter-diameter pipes. The treated water volume is approximately 13,100 m^3/day. The amount of solid materials retrieved from the station is predicted to be 360 m^3/month. The wastewater treatment plant's discharge pipe is 4700 m long and 0.5 m in diameter. The slope from the station's departure point is 65 m, and the volumetric flow rate of the treated water is 10.15 m/s. The station's average energy usage is around 9,923 kWh/day. Figure 4 shows a Google Earth view of the geography of the region where the sewage treatment facility is located, as well as the length and slope of the sewage pipe.

Figure 4. Image from Google Earth of the topography of the area where the sewage treatment plant is located and the length of sewage pipe elevations. *Source: Own.*

Mathematical analysis of hydroelectric energy

Water treatment facilities may create electrical energy in two ways:

- hydropower energy and
- biomass energy

Hydropower energy potential EH; kW

To calculate the energy potential of the input and outflow wastewater to the treatment plant, the water flow rate and the height from which the water drops must be determined. The generated energy may be computed as follows [18].

(1) $$E_H = \left[\rho g Q\left(H - h_f\right)\eta_t\right]_{\text{inlet}} + \left[\rho g Q\left(H - h_f\right)\eta_t\right]_{\text{outlet}}$$

where:

η_t represents the turbine's hydraulic efficiency, 90%, ρ is the density of water (kg/m^3),

g is the Earth's gravitational acceleration, 9.81 m/s^2.

The volumetric flow rate of water (m^3/s) is represented by Q. H is the height from which the water drops (m), and h_f is the pressure loss due to friction in the drainage pipe (m).

Biomass energy potential

The potential energy (E_B, kW) in the sludge may be calculated using the following equation [33]

(2) $$E_B = W_{SW}\ SR\ G_{SW} H_{BG}\ \eta_{\text{ele}}$$

where:

W_{SW} refers to the average amount of treated wastewater m^3/hr

G_{SW} represents the rate of biogas production from sludge and is estimated at 243 m3/ton [34].

SR represents the amount of sludge in wastewater estimated at 1.3 kg/m^3 [15].

H_{CH4} represents the calorific value of biogas (5.56 kWh/m^3) [35].

η_{ele} represents the electricity generation system's efficiency, 38% [1].

Total energy produced by the station

The total electricity (E_t, kW) that the wastewater treatment facility can generate on its own:

(3) $$E_t = E_H + E_B$$

Hydraulic calculations

Hydraulic calculations aim to find the indications' values in the available energy calculation equation (1).

The frictional losses hf are calculated from the Darcy equation [36]:

(4) $$h_f = \frac{8\ L\ f\ Q^2}{\pi^2\ g\ D^5}$$

where:

D represents the diameter of the drainpipe (m)

L represents the length of the drainpipe (m)

f represents the coefficient of friction, calculated from equation (5) [36]:

(5) $$f = \left\{1.8\ log\left[\frac{6.9}{Re} + \left(\frac{\varepsilon}{3.7\ D}\right)^{1.11}\right]\right\}^{-2}$$

where:

ε represents the roughness of the inner surface of the drainpipe (m)

Re represents the Reynolds number and is calculated from equation (6) [36].

(6) $$Re = \frac{4\ Q}{\pi D \nu}$$

where:
v represents the kinematic viscosity of water (m^2/s).

Economic and environmental calculations

The cost of generated energy unit (LCOE) is an economic measure used to estimate project profit and a reference for comparison with other production choices. The cost of environmental damage produced by carbon dioxide (C_{CO2}) may be used to compute LCOE using the following equation [37]:

(7) $$LCOE = \frac{\left(\frac{r(1+r)^n}{(1+r)^n-1}\right) \times \left(C_{C,H} + C_{C,B}\right) + \left(C_{O\&M,H} + C_{O\&M,B}\right) - C_{CO2}}{8760 \times E_t}$$

where:
$C_{O\&M}$ denotes the cost of operation and maintenance ($/year)
C_C the capital cost in $
E_t the power of the proposed system in kW (the number 8760 denotes the number of working hours in a year) n the device lifetime (30 years)
r the annual inflation rate (8%).
The subscripts H and B denote the two power generation systems: hydropower turbine and biogas-based generator.

The cost of environmental damage caused by CO2 gas can be calculated by the following equation [38].

(8) $$C_{CO2} = EF_{CO2} \times 8.760 \times E_t \times \emptyset_{CO2}$$

where:
EF_{CO2} represents the CO_2 emission factor of the electric power generation system in Libya, 0.983 kg CO_2/kWh
$\emptyset_{CO2}$ represents the environmental damage cost per unit ($/ton CO_2).
All costs in Equation (7) are included in Table 1.

Table 1. List costs of the proposed hybrid power generation system. *Source: Own.*

Item		**Cost**
1. Hydroelectric Energy System [17]		
1.1	Cost of Capital	7500 $/kW
1.2	Operation and Maintenance Cost	3.88 $/kW/year
2. Biomass Energy System [39]		
2.1.	Cost of Capital	1410 $/kW
2.2.	Operation and Maintenance Cost	3.5 % of Capital/year
3. Cost of Environmental Damage		15 $/ton CO_2

Hypotheses, limitations of study, and sources of uncertainties

To assist computations, researchers must make some assumptions, which in most circumstances have no substantial influence on the conclusions. In this study, the following hypothesis were established:

- There is a continual flow of sewage to and from the treatment facility.
- There are no losses in power transmission or consumption within the station.
- Biogas is composed of 50% methane and 50% CO_2.
- Due to a paucity of research in biomass energy, the biogas generation rate from sludge was set at 243 m^3/ton sludge [40].
- Ignoring the bulk of sludge in hydraulic and potential energy calculations since it accounts for a negligible amount (0.1%).
- Assuming that the hydraulic losses in the drainpipe and inflow pipes are equivalent.

The study's drawback is the lack of an investigation of the sensitivity of the implications of design and operation to the results, which the researchers will address in a further study.

The data is a source of uncertainty since there is a large variance in employment statistics, prices, and values, all of which are used by the study to establish economic and environmental indicators [41].

Results and Discussions

The planned hybrid system contains a Pelton turbine at the station's entry and a Francis turbine at the station's discharge pipe, as well as a biomass energy system that includes an anaerobic digester for sludge fermentation and a biogas-powered electric generator. Trucks deliver fermentation waste as organic fertilizer to grow trees and enhance soil quality. Figure 5 depicts the components of the proposed hybrid system as well as a representation of the energy and mass flow in the suggested technique.

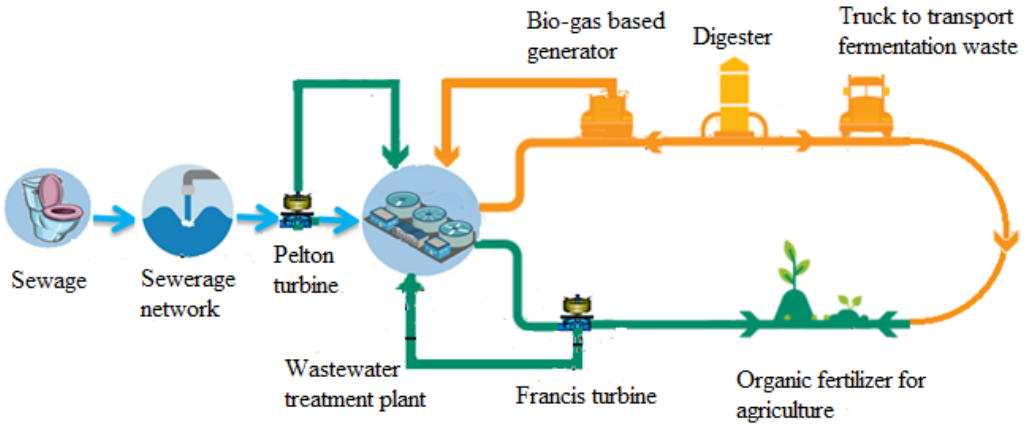

Figure 5. Energy and mass flow diagram in the proposed system. *Source: Own.*

The available energy may be computed using the energy and mass balance diagram illustrated in Figure 6 utilizing data obtained from the wastewater treatment facility in Gharyan, which is listed in Section 2.2.

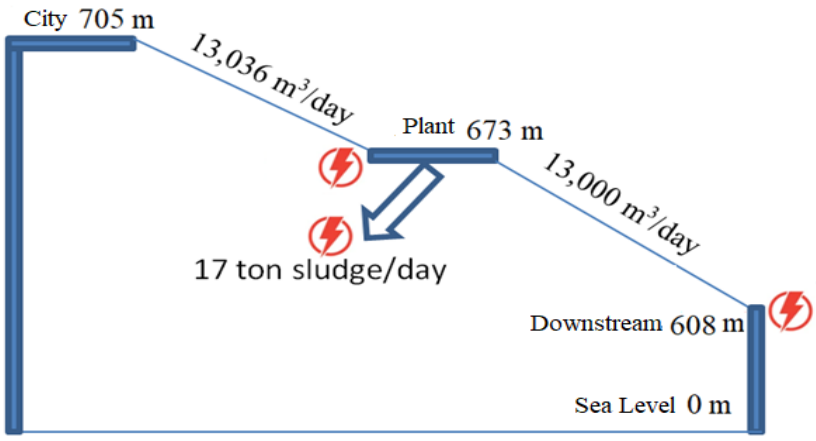

Figure 6. Energy and mass balance diagram. *Source: Own.*

The hydropower energy potential

Equation (2) is used to calculate the quantity of hydroelectric energy (EH) in kW in the treated water in the station at the input and discharge pipes.

$$E_H = (1000) \times (9.81) \times (0.151) \times (0.9) \times [((673 - 608) - 5) + ((710 - 673) - 5)] \cong 129 \text{ kW} \quad (9)$$

The biomass energy potential

The amount of energy potential (EB) in kW in sludge can be estimated from equation (3):

$$E_B = (542.92)(1.3)(0.243)(5.56)(0.38) \cong 362 \text{ kW} \quad (10)$$

Therefore, the total energy available from the water treatment plant is estimated at 490 kW. This covers 87.5% of the station's electrical energy consumption.

Economic-environmental analysis

Table 2 shows the CO_2 emission factor for several fuel types based on several indicators [42].

Table 2. CO_2 emission factor based on several units.

Fuel Type	**Volume unit kg CO_2/m^3**	**Thermal energy unit kg CO_2/GJ**	**Electrical energy unit kg CO_2/MWh**
Biofuel	1.06	84.2	441.4
Natural gas	1.77	55.8	433.0
Light fuel	2,752	71.0	849.2
Heavy fuel	3,156	81.3	909.7
Crude oil	3,266	92.5	966.2

Therefore, the amount of CO_2 gas (m_{CO2}) emitted annually from the proposed system can be estimated as follows:

(11) $$m_{CO2} = 0.4414 \times 362 \times 8760 = 1{,}400\ ton\ CO_2/year$$

The CO_2 emission factor for Libya's power production system is estimated to be around 1.037 kg CO_2/kWh [1]. As a result, the amount of CO_2 gas trapped from emission into the atmosphere may be approximated as follows:

(12) $$0.875 \times 9{,}923 \times 365 \times 1.037 \times 10^{-3} - 1{,}400 = 1{,}886\ \text{ton}\ CO_2/year$$

The amount of CO_2 gas released by the station per year is equal to:

(13) $$(1 - 0.875) \times 9{,}923 \times 365 \times 1.037 \times 10^{-3} + 1{,}400 = 1{,}870\ \text{ton}\ CO_2/year$$

Thus, using equation (9) the cost of CO_2 gas is projected to be \$140,250 per year. As a result, the LCOE of the station's electrical energy may be determined using equation (8) as follows:

(14) $$LCOE = \frac{\left(\frac{0.08(1.08)^{30}}{(1.08)^{30}-1}\right) \times (7500 \times 129 + 1410 \times 362) + (3.8 \times 129 + 0.035 \times 1410 \times 362) - 1886 \times 15}{8760 \times 490} = \$0.0283\ per\ kWh$$

Knowing that the General Electricity Company purchases electrical energy produced from renewable energy providers at \$0.1/kWh, the annual net profit from this system is estimated at approximately \$307,765/year. The capital recovery period is estimated at around 3.44 years.

Analysis of the general situation of wastewater treatment plants in Libya

Approximately 200 sewage treatment facilities were erected across the nation between 1966 and 1990, however the majority are no longer in use due to their age. The main wastewater treatment plants are located in Tripoli (capacity: 101,000 m^3/day), Misurata (capacity: 24,000 m^3/day), and Sirte (capacity: 21,000 m^3/day). The remaining stations are modest and medium-sized, with design capacities ranging from (370-6,700 m^3/day). The volume of wastewater generated each day is projected to be 1,324,054 m^3. Only 145,800 m^3/day of this total gets processed, accounting for 11% of total wastewater production. The remainder of the wastewater is discharged untreated into the sea, valleys, and manmade lakes, inflicting serious harm to the surrounding ecology. Because no information on the geographical location of these factories is currently available, just the available sludge energy will be computed. The available energy may be determined using Equation 3 as follows:

(15) E_S= (55,169)(1.3)(0.243)(5.56)(0.38)≅36,820 kW

Perhaps the most significant loss due to neglecting the critical role of this sector and leaving wastewater treatment plants without maintenance development, in addition to environmental damage and the loss of 37 MW of sustainable energy, is the loss of approximately 4 million cubic meters per day in a desert country that lacks water, which could have made a difference in the area of vegetation cover of the state, protecting cities from sandstorms, desert encroachment, and the establishment of forests and natural reserves.

The loss of almost 4 million m^3/day in a desert nation without water, which might have made a difference in the state's vegetation cover, protecting towns from sandstorms, desert encroachment, a loss of 37 MW of sustainable energy, is possibly the most significant loss as a result of abandoning the crucial role of this sector and leaving wastewater treatment plants without maintenance.

Impacts of the research results on economy, environment and society

To counteract the degradation of terrestrial and marine ecosystems, it is imperative to focus on wastewater treatment stations, monitoring, and continuous development. There is a growing interest in recycling these resources, leading to the preservation of natural resources, decreased energy consumption, and reduced pollution from burning fossil fuels. Wastewater treatment plants, within this framework, are acknowledged as sustainable sources of irrigation water, organic fertilizer, and energy. The implementation of such projects can yield various eco-environmental and socio-economic impacts, including:

- Reducing irrigation water usage by incorporating treated water from the station.
- Conserving fossil fuels for energy and minimizing CO_2 emissions through the use of renewable energy sources.
- Preserving natural resources and essential elements like phosphorus for fertilizer production.
- Creating new job opportunities for the local community.
- Maximizing economic returns by utilizing treated wastewater in forestry for cultivating trees and establishing wood industries.
- Contributing to forests' roles in purifying the air, moderating the climate, combating desertification and sand encroachment, preserving vegetation, and protecting cities and residential areas from sand and dust storms.

Conclusions and future studies

The research focused on evaluating the energy potential of the wastewater plant in Gharyan city. The article introduced a hybrid generation system comprising two hydroelectric plants and a biogas-powered power plant using sludge fermentation in a biomass reactor. Economic and environmental assessments were conducted to demonstrate the viability of this proposed system. Projections indicate that the hybrid system could generate 490 kW of electrical power, covering 87.5% of the plant's electricity needs.

The estimated investment for implementation is $1,478,000, with an annual maintenance cost of approximately $18,355, and a production cost of 2.83¢/kWh. Notably, the proposed hybrid system is anticipated to prevent the annual release of 1886 tons of CO_2, resulting in an annual cost saving of $28,290 for the plant. Future plans involve extending the study to all sewage plants in Libya by conducting topographic surveys to identify stations situated at higher elevations, thereby assessing their potential energy contribution.

Author Contributions

"Conceptualization, Nassar and Manager; methodology, Nassar and El-Khozondar; formal analysis, Khaleel, Ahmed and Alsharif, data collection, Manger and Elzer; writing—original draft preparation, Nassar and Awad; writing—review and editing, Hafez. All authors have read and agreed to the published version of the manuscript."

Declarations

Ethical Approval: (Not applicable)
Availability of data and materials: (The data are available at request)

Conflict of interest

There is no conflict of interest.

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References:

[1] A.A. Makhzom, A.M. Eshdok, Y.F. Nassar, S.Y. Alsadi, T.H. Foqha, M.A. Salem, I.M. Alshareef, H.J. El-Khozondar, Estimation of CO_2 emission factor for Power Industry Sector in Libya, in: 8th Int. Eng. Conf. Renew. Energy Sustain. IeCRES 2023, IEEE, 2023: pp. 1–6. https://doi.org/10.1109/ieCRES57315.2023.10209528.

[2] Y.F. Nassar, K.R. Aissa, S.Y. Alsadi, Air Pollution Sources in Libya , Res. Rev. J. Ecol. Environ. Sci. 6 (2017) 63–79.

[3] A. Almabrouk, S. Abulifa, The technology of renewable energy and its role in achieving sustainable development, Int. J. Electr. Eng. Sustain. 1 (2023) 1–9.

[4] M. Andeef, K. Bakouri, B. Ahmed, A. Gait, F. El-Batta, T. Foqha, H. Qarqad, The role of renewable energies in achieving a more secure and stable future, Int. J. Electr. Eng. Sustain. 1 (2023) 11–20.

[5] Y.F. Nassar, H.J. El-Khozondar, W. El-Osta, S. Mohammed, M. Elnaggar, M. Khaleel, A. Ahmed, A. Alsharif, Carbon footprint and energy life cycle assessment of wind energy industry in Libya, Energy Convers. Manag. 300 (2024) 117846. https://doi.org/10.1016/j.enconman.2023.117846.

[6] A. Elmariami, W. El-Osta, Y. Nassar, Y. Khalifa, M. Elfleet, Life Cycle Assessment of 20 MW Wind Farm in Libya, Appl. Sol. Energy (English Transl. Geliotekhnika). 59 (2023) 64–78. https://doi.org/10.3103/S0003701X22601557.

[7] Y.F. Nassar, H.J. El-Khozondar, W. El-Osta, S. Mohammed, M. Elnaggar, M. Khaleel, A. Ahmed, A. Alsharif, Carbon footprint and energy life cycle assessment of wind energy industry in Libya, Energy Convers. Manag. 300 (2024) 50–68. https://doi.org/10.1016/j.enconman.2023.117846.

[8] A.M. Jary, M. Elmnifi, Z. Said, L.J. Habeeb, H. Moria, Potential wind energy in the cities of the Libyan coast, a feasibility study, J. Mech. Eng. Res. Dev. 44 (2021) 236–252.

[9] Y.F. Nassar, H.J. El-khozondar, G. Ghaboun, M. Khaleel, Z. Yusupov, Abdussalam Ahmed; Abdulgader Alsharif, Solar and Wind Atlas for Libya, Int. J. Electr. Eng. Sustain. 1 (2023) 27–43. https://ijees.org/index.php/ijees/index.

[10] A. Ghayth, Z. Yusupov, M. Khaleel, Performance Enhancement of PV Array Utilizing Perturb & Observe Algorithm, Int. J. Electr. Eng. Sustain. 1 (2023) 29–37.

[11] M. Abdunnabi, I. Rohuma, E. Endya, E. Belal, Review on solar water heating in Libya, Sol. Energy Sustain. Dev. J. 7 (2021). https://doi.org/10.51646/jsesd.v7i3.76.

[12] B. Belgasim, Y. Aldali, Review on Solar Thermal Electricity in Libya, Sol. Energy Sustain. Dev. J. 7 (2021). https://doi.org/10.51646/jsesd.v7i3.78.

[13] S.M. Abdulwahab, Y.F. Nassar, H.J. El-khozondar, M. Khaleel, A. Abdussalam, International Journal of Electrical Engineering Meeting Solar Energy Demands : Significance of Transposition Models for Solar Irradiance , Int. J. Electr. Eng. Sustain. 1 (2023) 90–105. https://ijees.org/index.php/ijees/article/view/52.

[14] M. Elmnifi, M. Alshilmany, M. Abdraba, Potential of Municipal Solid Waste in Libya for Energy Utilization, Acta Mech. Malaysia. 2 (2019) 11–15. https://doi.org/10.26480/amm.01.2019.11.15.

[15] M. Elmnifi, M. Amhamed, Future of Waste to Energy : Case study of Libya, Adv. Ind. Eng. Manag. (AIEM). 8 (2019) 1–4.

[16] M.M. Muetaz Mohammed, S.B. Boghandora, R.H. Hassan, A.J. Jirhiman, A.A. Ali Ahmeedah, Influence of pH and the Insulation of Reactor on The Biogas Production of Livestock Waste by Batch Anaerobic Reactor, Sol. Energy Sustain. Dev. J. 11 (2022) 1–12. https://doi.org/10.51646/jsesd.v11i2.140.

[17] M. Ashur, I. Bengharbia, Effect of Temperature and pH on Biogas Production From Organic Fraction-MSW, Sol. Energy Sustain. Dev. J. 4 (2015) 22–28. https://doi.org/10.51646/jsesd.v4i1.80.

[18] Y. Nassar, I. Mangir, A. Hafez, H. El-Khozondar, M. Salem, H. Awad, Feasibility of innovative topography-based hybrid renewable electrical power system: A case study, Clean. Eng. Technol. 14 (2023) 100650. https://doi.org/10.1016/j.clet.2023.100650.

[19] Y.F. Nassar, M.J. Abdunnabi, M.N. Sbeta, A.A. Hafez, K.A. Amer, A.Y. Ahmed, B. Belgasim, Dynamic analysis and sizing optimization of a pumped hydroelectric storage-integrated hybrid PV/Wind system: A case study, Energy Convers. Manag. 229 (2021) 113744. https://doi.org/10.1016/j.enconman.2020.113744.

[20] N.A. Fadhil, M. Elmnifi, O.D.H. Abdulrazig, L.J. Habeeb, Design and modeling of hybrid photovoltaic micro-hydro power for Al-Bakur road lighting: A case study, Mater. Today Proc. 49 (2021) 2851–2857. https://doi.org/10.1016/j.matpr.2021.10.072.

[21] IHA, Facts about hydropower, Int. Hydropower Assoc. (2021) 1–5.

[22] Y.F. Nassar, H.J. El-Khozondar, N.M. Abouhmod, A.A. Abubaker, A.A. Ahmed, A. Alsharif, M.M. Khaleel, M. Elnaggar, R.J. El-Khozondar, Regression Model for Optimum Solar Collectors' Tilt Angles in Libya, in:

8th Int. Eng. Conf. Renew. Energy Sustain. IeCRES 2023, IEEE, 2023: pp. 1–6. https://doi.org/10.1109/ieCRES57315.2023.10209547.

[23] M. Khaleel, Z. Yusupov, N. Yasser, H.J. El-Khozondar, Enhancing Microgrid Performance through Hybrid Energy Storage System Integration: ANFIS and GA Approaches, Int. J. Electr. Eng. Sustain. . 1 (2023) 38–48. https://ijees.org/index.php/ijees/index.

[24] A. Ahmed, O. Abd Al Aziz, Y. Nassar, Power management strategy and sizing optimization techniques for hybrid energy systems considering feature selection: mini review, North African J. Sci. Publ. 1 (2023) 38–48. https://najsp.com/index.php/home/article/view/55/41.

[25] A.M. Elbreki, H. Moria, A.M. Ahmed, M. Elmnifi, A. Abdulmula, Optimization and Performance Evaluation of Hybrid Renewable System for Minimizing CO_2 Emissions in Libya: A Case Study, Int. J. Renew. Energy Res. 10 (2020) 1725–1734. https://doi.org/10.20508/ijrer.v10i4.11265.g8065.

[26] T. Uchiyama, S. Honda, T. Okayama, T. Degawa, A Feasibility Study of Power Generation from Sewage Using a Hollowed Pico-Hydraulic Turbine, Engineering. 2 (2016) 510–517. https://doi.org/10.1016/J.ENG.2016.04.007.

[27] J.C. Radcliffe, The water energy nexus in Australia – The outcome of two crises, Water-Energy Nexus. 1 (2018) 66–85. https://doi.org/10.1016/j.wen.2018.07.003.

[28] R.M. Llácer-Iglesias, P.A. López-Jiménez, M. Pérez-Sánchez, Hydropower technology for sustainable energy generation in wastewater systems: Learning from the experience, Water (Switzerland). 13 (2021) 3259. https://doi.org/10.3390/w13223259.

[29] C. Power, A. McNabola, P. Coughlan, Development of an evaluation method for hydropower energy recovery in wastewater treatment plants: Case studies in Ireland and the UK, Sustain. Energy Technol. Assessments. 7 (2014) 166–177. https://doi.org/10.1016/j.seta.2014.06.001.

[30] Suez, As Samra wastewater treatment plant a major asset for Jordan, (2017).

[31] B. BARAN, Usage of Waste Water Treatment Plants Hydroelectric Energy for Urban Lighting Energy: The Case of Turkey, Uluslararası Muhendis. Arastirma ve Gelistirme Derg. 13 (2021) 750–762. https://doi.org/10.29137/umagd.882607.

[32] Gharyan, https://en.wikipedia.org/wiki/Gharyan, (n.d.).

[33] H. Al-Najjar, C. Pfeifer, R. Al Afif, H.J. El-Khozondar, Estimated view of renewable resources as a sustainable electrical energy source, case study, Designs. 4 (2020) 1–18. https://doi.org/10.3390/designs4030032.

[34] D. Van Der Horst, S. Martinat, J. Navratil, P. Dvorak, P. Chmielova, What can the location of biogas plants tell us about agricultural change? A case study from the Czech Republic, Deturope. 10 (2018) 33–52. https://doi.org/10.32725/det.2018.002.

[35] A. Pertiwiningrum, M.A. Wuri, A.W. Harto, R. Budiarto, M. Gozan, Heating value enhancement by biogas purification using natural zeolite and rice straw-based biochar, Int. J. GEOMATE. 16 (2019) 80–85. https://doi.org/10.21660/2019.55.4715.

[36] E. Dekam, S. Alghoul, Fluid mechanics-fundamentals and applications, Noor publishing Company, Germany, 2018.

[37] Y.F. Nassar, S.Y. Alsadi, H.J. El-Khozondar, M.S. Ismail, M. Al-Maghalseh, T. Khatib, J.A. Sa'ed, M.H. Mushtaha, T. Djerafi, Design of an isolated renewable hybrid energy system: a case study, Mater. Renew. Sustain. Energy. 11 (2022) 225–240. https://doi.org/10.1007/s40243-022-00216-1.

[38] M. Abdunnabi, N. Etiab, Y.F. Nassar, H.J. El-Khozondar, R. Khargotra, Energy savings strategy for the residential sector in Libya and its impacts on the global environment and the nation economy, Adv. Build. Energy Res. 17 (2023) 379–411. https://doi.org/10.1080/17512549.2023.2209094.

[39] L. Jarrar, O. Ayadi, J. Al Asfar, Techno-economic aspects of electricity generation from a farm based biogas plant, J. Sustain. Dev. Energy, Water Environ. Syst. 8 (2020) 476–492. https://doi.org/10.13044/j.sdewes.d7.0302.

[40] H.J. El-Khozondar, F. El-batta, R.J. El-Khozondar, Y. Nassar, M. Alramlawi, S. Alsadi, Standalone hybrid PV/wind/diesel-electric generator system for a COVID-19 quarantine center, Environ. Prog. Sustain. Energy. 42 (2022). https://doi.org/10.1002/ep.14049.

[41] Y.F. Nassar, S.Y. Alsadi, Assessment of solar energy potential in Gaza Strip-Palestine, Sustain. Energy Technol. Assessments. 31 (2019) 318–328. https://doi.org/10.1016/j.seta.2018.12.010.

[42] Y.F. Nassar, M.A. Salem, K.R. Iessa, I.M. AlShareef, K.A. Ali, M.A. Fakher, Estimation of CO_2 emission factor for the energy industry sector in libya: a case study, Environ. Dev. Sustain. 23 (2021) 13998–14026. https://doi.org/10.1007/s10668-021-01248-9.

DISPLACEMENT PARADIGM TOWARDS DIGITAL MUSIC DISTRIBUTION IN THE RECORDING INDUSTRY

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Highlight
Framing the study by utilising the theory of diffusion of innovation and applying factor analysis (using SPSS. 26. S) in developing a supply chain innovation music model brought the context of digital music distribution. Digital music distribution makes music distribution more resilient and better enabled to displace the superfluity of physical music distribution in the recording industry. In addition, artists have more ways to connect with their fans and opportunities to share their work in diverse and creative ways.

Abstract
Digital music streaming and downloading platforms supervene the stymied superfluity of physical music distribution in the recording industry. The significant transition seems to provide quasi-real-time increased music consumption. The purpose of the study is to identify the challenges associated with the paradigm shift to the digital trajectory of music regarding global market demand and to establish the extent to which digital diffusion innovations influence digital music distribution and consumption in the recording industry. The exploratory research study employed univariate and multivariate statistical analysis to analyse the data collected from 217 musicians. The study found that the customer base of physical retail stores is dwindling due to the increasing number of independent artists and technologically compatible media devices that encourage music streaming and downloads. The practical implications ensue the amplitude of music downloads that is proffered by modular technological developments, such as the buttress of smartphones while it predicates the perspicacity of innovative digital technologies to create independent shrewd music entrepreneurs.

Keywords
Digital music distribution; e-commerce; disintermediation; diffusion of innovation.

Introduction

The music falls within the creative industry and offers global fans a delightful hedonic experience. The advent of digital technologies has transformed the nature of people's musical experiences. Digital recording has the propensity to produce new entrepreneurs through a revolutionary digital operations management cycle. While online distribution systems have facilitated product availability, mobile devices are the pervasive mode for listening to and consuming music. At the same time, social media provides dyadic (Fan-Artist/fan-fan linkage) platforms for sharing, interacting and learning about music [1]. Fans can now listen to music on the move, from the daily commute by car, taxi or bus to jogging through the park and gym facilities. Pervez and Haq [2] note that digital music is "packaged in a flexible, structured way that combines sound with rich, layered metadata to support interactive and adaptive musical experiences". This expanded music experience offers fans a highly immersive and deeply engaging, multi-layered soundscape [3]. The study examined the trend of online music channels, and the distribution strategies employed by record companies and musicians to cope with these changes, as well as the challenges experienced in this journey. The study used the diffusion of innovation theory and crafted the literature review on digital music distribution, disintermediation/reintermediation, and innovative transformation. The quantitative research design was utilized to generate empirical findings. The growth of digital streaming and downloading from Internet platforms entices music retailers and recording companies for direct digital distribution. Conversely, piracy has yielded fewer sales of compact disks (CDs) by music retail outlets with brick-and-mortar stores, undermining their financial viability. Physical retail stores have ceased their operations and music customers have swapped to electronic commerce businesses such as Amazon.com, Kalahari.net, Takealot.com and Loot and streaming on Spotify, iTunes, Deezer and so on.

The study observes the digital paradigm of the distribution supply chain that it resonates with lower cost structure, maximum consumption, the propensity to entrepreneurship and the displacement of physical inventory with virtual inventory. The technology push effect describes developments in technology, including increased awareness, the rise of constrained Internet and broadband accessibility and intense competition that outwits the physical retail music stores. The digital downloading platforms offer access to digitalised music distribution and a quasi-real-time consumption cycle. The trajectory displaced the existing brick-and-mortar business, and the evolving information highway increases global customer demand and the level of supply chain responsiveness (from the supply side) points to market changes in supply chain distribution channels in the music industry. Against this background scenario, the study cogitates on technological innovations that are expected to enhance the digital distribution of music on the Internet. Although the distribution systems have posed challenges within the supply chain network, the foreground scenario for this study attempts to develop tentative model for supply chain digital music distribution, consumption, responsiveness and legitimacy cycles. This study objective deductively delves into the challenges associated with the paradigm shift to the digital trajectory of music global market demand; it ascertains musicians' perceptions of the transition and how it has affected both artists and the industry. It was also essential to establish the extent distribution operations processes are in sync with digital diffusion supply chain innovations and whether they impact digital music distribution and consumption in the recording industry.

Digital Perspective of the Music Industry

South Africa's nascent music industry reflects a slightly developed product of genres on the African continent [4]. The hegemony of international music businesses primarily absorbs the major ownership share [5] ranging from five multinational companies, namely, EMI, Sony, Universal-Vivendi, Time Warner and Bertelsmann (BMG) that control the production and distribution of recorded music [6]. An ambitious digitisation project undertaken by Mpumalanga province in South Africa epitomised the willingness and capability of conventional and native digital artists to engage in digital music production and distribution. According to Netshakhuma [7], a lack of resources hindered the successful implementation of the project.

Skulan [8] also proffered that a lack of skills and knowledge can prevent musicians from digitising their operations and distribution systems. Vermeulen [9] observes that sales of recorded music in physical format in South Africa are shrinking faster than that observed at the global level. Music streaming allows customers to listen to music on their preferred device (PC, iPod, smartphone, tablet, notebook, etc.) without owning a digital music file or a physical format (such as a CD, tape or vinyl). The music files are stored by the streaming provider on a server and are provided to the customer on demand when he/she logs in on a website or mobile app. Subscription services like Apple Music, Joox, Google Play Music, Tidal, Simfy Africa, Rara, iTunes, and Deezer are major companies in the market and are responsible for the majority of total digital sales. Knopper [10] notes that "digital music sales saved the record industry following years of piracy". The exponential growth of digital music distribution is underpinned by the rapid penetration of smartphones, and embryonic streaming services such as Apple Music are gaining a larger market share. Prominent players in South Africa include Google Play, Rara, Simfy Africa and Deezer.

Technology is fundamentally changing the landscape of most consumer-oriented businesses. Consumer buying behaviours and demand patterns are significantly affected by high Internet penetration, ubiquitous information availability, and rapidly growing social networks. This has a significant impact on consumer-oriented industries such as music, publishing, consumer electronics, retail and financial services. Consumers' propensity to adopt technology has a major impact on supply chains through social networks and Internet-enabling digital platforms. The application of emerging technologies to supply chains enables organisations to deliver superior value to customers. Digital music is defined as "a particular combination of data and sound that exists as an entity in and of itself for sale or acquisition in online outlets via computers or other digital portable devices" [11]. Digital supply chains facilitate the exchange of information and enable superior collaboration and communication across digital platforms, resulting in improved reliability, agility and effectiveness. It is thus essential for the music industry to integrate digital production, distribution and consumption into its overall supply chain strategy to generate and measure long-term value. Digitalisation refers to "the increasing penetration of digital technologies in society with the associated changes in the connection of individuals and their behaviour" [12,13]. Developed economies such as the United States, Japan and the United Kingdom have achieved a high level of digitalisation, created millions of job opportunities and boosted economic prospects. Digitisation could assist the South African economy to contribute to the achievement of national imperatives such as improved productivity, welfare, and economic growth. Ultimately it could reduce inequality, poverty, and unemployment,

and also promote social transformation [14].

Theoretical Framework

The symbiotic leverage of disruptive technology and reverberating innovation entrench the culmination of digital music streaming and downloading. Music fans credulously adopt an innovation of digital music distribution platforms, and the innovation will be diffused among the population. Diffusion is "the process by which an innovation is communicated through certain channels over time among the members of a social system" [15,16]. Wu and Chuang [17] concur with Lin and Huang [18] in defining innovation system diffusion as "a process from internal diffusion among functional units within an organisation to external diffusion across inter-organisational trading partners when innovation becomes an integral part of the value activities". Mbhele [19] adds from Mbhele's Law of Oscillation that electronic supply chain management (e-SCM) systems diffusion is "a process from internal diffusion among functional units within an organisation to external diffusion across extended supply chain enterprises" including individual innovativeness, innovation-decision process, perceived attributes of innovations, adoption rate, and different adopter categories with elements of innovation, communication channels, time, and social system. An agile supply chain system enjoys a certain level of flexibility that creates considerable resilience in responding to the disintermediation of the retail music industry. Rogers [15] describes the innovation-decision process as "an information-seeking and information-processing activity, where an individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation". According to Rangaswamy and Gupta [20], the study of adoption behaviour and the diffusion process for digital products is "based on concepts and theories of individual decision-making and allows one to segment and profile customers based on the time of adoption and on their inclination to adopt an innovation. The Diffusion of Innovation theory focuses on how, why and at what rate novice ideas and technology are disseminated across cultures and generations. It explains how, as time passes, an idea or product gains market share and spreads in a specific social system. The result of such diffusion is that people move away from traditional physical music distribution and adopt new digital distribution ideas, behaviour or products. This theory is used here to establish how early adopters influence the adoption of innovation or digitalised music in the recording industry. The Diffusion of Innovation theory has been adopted in research in the "field of social media, about the adoption of Twitter Hashtags" [21]; "mobile banking technology adoption" [22]; "the radio broadcasting industry" [23] and "the adoption and diffusion of innovation in retro-industries" [24]. The digital business platforms entice the better utilisation of word-of-mouth and entrench market assimilation and communication, thus directly impacting the diffusion of digital music and complementary technologies as well as new ideas and products.

Porter's [25] diamond model provides a framework for the analysis of competitive advantage. Porter states that competitiveness relies on four interrelated components: (1) factor conditions, (2) demand conditions, (3) related and supporting industries, and (4) firm strategy, structure, and rivalry. Factor conditions in South Africa include the positioning of the music industry in the production cycle and the availability of innovative and skilled labour. Firm strategy, structure, and rivalry refer to the conditions that govern how companies are created, organised, and managed, as well as the nature and intensity of domestic competition [25]. The article adopts the diamond approach based on the attributes identified by Parc and Kim [26], namely producers (factor conditions); consumers (demand conditions); distributors (related and supporting industries); and business context (firm strategy, structure, and rivalry). The rapid digitisation of the music industry has changed consumer purchasing behaviour across the world. The process of platformisation appears to fundamentally transform the organisation of cultural production, distribution and marketing. Spotify in particular seems to have become "a model for other services that use digital technology to transform the distribution of cultural goods" [27]. Music distributors, musicians, artists, and companies that share content on these platforms gradually master a variety of tools and strategies that enable them to stand out in these crowded environments. Prey [28] advocates that artists should orient their music towards inclusion on featured playlist shows.

Science of innovation and digital music transformation

The science of innovation for the creative industry is evolving continuously based on the underlying disruptive technologies. According to Omidi, et al., [29], the main difference between service innovation and product innovation is that in the latter, "the audience achieves the new products and has a sense of ownership of them"; while in the former, "the audience receives the services and does not necessarily purchase them in the form of a product, but considers them as a service experience". Modern-day supply chains span multiple geographical boundaries in different socioeconomic settings, each requiring specific checks and balances to ensure the smooth functioning of the chain. The Fourth Industrial Revolution [30] is indeed a revolution, bringing digital technologies

into developed and developing economies that impact modes of interaction, production processes and global value chains [31]. The OECD [32] notes that disruptive innovations in distribution can result in a situation where firms' investment "costs are too high" and "products are not suitable for online purchases". Nevertheless, music distribution services are moving from download shops to online streaming services. The innovation of the CD brought new growth dynamics to the sector while allowing for integration into established markets, and production, marketing and distribution models, as well as copyright and contractual frameworks [29,33]. While major music groups such as Universal/Polygram, Sony Music Entertainment, EMI, Warner Music and Bertelsmann Music previously enjoyed the lion's share of global music sales, the market is now dominated by free music file-sharing forums on the Internet, marked most notably by the rise of Napster. Hull, Hutchison and Strasser [34] trace the evolution and transformation of the music industry through three stages, namely, historical/agricultural (live performances, mobile musicians and music fans), industrial (music delivery via products, recorded tapes and mass media) and informational (content via digital technology, mobiles and the Internet). This transformation was hindered by the non-commercial exchange of file-sharing networks until Apple's iTunes and the establishment of commercial download retailers enabled an extension of the old distribution model on a digital basis. In this context, 'transformation' refers to a radical reorientation that substantially changes a sector's technological basis and, concomitantly, its socioeconomic structures [33].

The transformation process has created a disintermediation chain of modus operandi although music companies remain central producers and rights holders. Parc and Kim [26] opine that the digital music value chain has also ingeniously transformed and infused enterprising music trajectory from analogue to digital; offline to online; albums to songs; specialisation to integration; domestic providers to international suppliers; audio sound to visual images; possession to accessing; and from limited integration to a synergistic network. Digital transformation technologies such as the Cloud, the Internet of Things (IoT), Blockchain (BC), Artificial Intelligence (AI), and Machine Learning (ML) have been adopted by organisations as part of the transformation process. Blockchain technology presents an opportunity to create secure and trusted information control mechanisms [35]. It enables secure and authenticated copyrights and limits the magnitude of piracy [2]. In deploying security technologies like BC, it is important to understand the implications of smart contracts, their integration in workflows, and their effectiveness in complex resource-constrained settings, as in developing countries such as South Africa. Furthermore, understanding the implications of secure and non-erasable technologies like BC is relevant for regulation [36]. On Spotify, copycats, endless birthday songs, and other attempts at visibility like Matt Farley's extensive catalogue, are part of the business model adopted by artists to earn a sustainable income. South African musicians are thus called upon to embrace technological advancement to enhance the competitiveness of the creative industry.

Music distribution systems that predated digitalised distribution involved a distributor that physically distributed CDs in bulk from record labels and warehouses and shipped them on demand to retail outlets or directly to consumers. This entailed a centralised distribution system with a push supply chain. Bowersox et al. [37] describe direct distribution as "the services of premium transport combined with information technology to rapidly process customer orders and achieve delivery performance" Retailers, including supermarkets, live music venues and large-scale record stores place the physical product on their shelves and sell it directly to customers. The operable compact discs (CD) are becoming an obstinate problem by trivialising and circumscribing the quality of sound, lyrics and despicable proclivity of scratches and damages. The topsy-turvy ecosystem of direct music distribution has subsided and vanquished the deluge of intermediaries. The heterodox model epitomises a desideratum seamless digital value chain capable of valorising the coalesce of the digital music ecosystem. The verity of innovation should aver the amplified dexterity of independent entrepreneurship practises and posterity of digital artists underpinned and entrenched by transcending the advent of 4th industrial revolution technologies. The lack of a better description, the semblance of music normality is earmarking for digital transformation with the quixotic desire to do good with slight abrupt enthusiasm for new entrepreneurs.

Digital transformation refers to "the alteration of the business models by the use of innovative and technological processes that leads to immense changes in the behaviour of the society and the consumer" [38]. Technological innovation within various industries has transformed the behaviour of organisations, market structures and individuals. Sundaram, et al. [13] note that digital transformation transforms business competencies, procedures, practices and models to strategically exploit the opportunities emanating from emerging technology. Although emerging technologies have immense potential as equalisers, without sound governance, they could intensify the digital divide in society [2].

Reintermediation in the supply chain

The digital platform vests in the realism of reintermediation where "a reintroduction of an intermediary between supplier and consumer" [39]. Carr [40] defines reintermediation as "the reformulation, realignment and pruning of intermediaries but without total elimination". The reintermediation approach enhances the magnitude of "partnering for access, technology licensing, partnering for content and partnering for application development" [39]. However, Sarkar et al. [41] argue that intermediation is a structural feature of the electronic marketplace and its role is not simply taken over by producers. 'Agile distribution' is defined as the link key among the players in the music industry that focuses on the relationship between production and music usage [42]. Physical or electronic distribution is among the most critical activities in marketing musical products. Digital distribution involves the legal sale of song files through the Internet which represents the ownership model. Digital music reform takes place at the economic, social, and technological levels. Advanced technologies, supply chain resilience, and organisational agility are required for the South African music industry to achieve a sustainable growth trajectory. Music has long been part of the capitalist system, but this is now seen as weakening the music sector as, "in a digital economy that favours 'free' or advertising-subsidized content, the big tech oligopoly is able to use cultural content as a loss leader and promotional medium in efforts to drive sales elsewhere" [43]. Digital servitisation is a service strategy that exploits digital breakthroughs such as smart connected products, industrial Internet platforms, predictive analytics, digital offerings, and advanced services [44,45]. Combining servitisation and digitalisation can make firms less dependent on travel and human interaction. Servitisation refers to a firm's transition from a product-centric business logic, focusing on selling products, to a more service-oriented business logic that focuses on facilitating customer value creation through the provision of advanced services and solutions that better fulfil customers' specific needs [46]. It can make firms more resilient and better able, when faced with adversity, to 'bounce back' and emerge ahead of the competition. Resilience can be built on redundancy (or resourcefulness), which refers to slack in modular resources (production facilities, stock of material, etc.) that can be rapidly activated to reconfigure the value network [47]. However, the transformation underpinning the development and implementation of digital offerings is generally a long-term process [48].

Digital distribution of sound recordings via platforms has broken the established royalty deals based on sales as streaming has become an increasingly dominant mode of access to music; it now constitutes more than half of the music industry revenue in major markets [49]. The business model for music streaming differs from previous arrangements where the royalty paid to songwriters and performers was a percentage of sales. In the case of streamed music, payment is based on revenue from both subscriptions and ad-based free services. Haskell and Westlake [50] observe that while the distribution of music embodied in physical goods (printed music and CDs) can be controlled by the seller, intangible goods require intervention in the market to control misappropriation by non-payers (piracy), copyright to provide statutory protection and an economic incentive for content creation. Copyright law confers various rights to protect musical works by upstream creators (songwriters) and further downstream, protects rights in performers' performances and sound recordings [51,52]. The digital content market is underpinned by social networking and digital technological innovations. Chaffey [53] and Weinberg [54] state that, with the increased number of social network sites (SNS), social networking has become a focal reason for the music industry to adopt the pull strategy. Chaffey [53] defines social media marketing as "monitoring and facilitating customer-customer interaction and participation throughout the web to encourage positive engagement with a company and its brands. Interactions may occur on a company site, social networks and other third-party sites". It constitutes an amplitude of surging omnichannel distribution system to subside the derelict mode of brick and mortar.

Table 1. Global Recorded Music Industry Revenue 2017 to 2019 (in billion US$). *Source: [55].*

Year	Total Physical	Revenue (in US-$ billion) of that (in %)	Downloads & other digital	Streaming	Performance Rights	Synchronisation
2017	17.0	30.6	15.3	38.2	13.5	2.4
2018	18.7	24.6	9.6	49.2	13.9	2.7
2019	20.2	21.3	6.9	56.4	12.9	2.5

In 2018, the remaining three major players in the music industry, Universal Music Group, Sony Music Entertainment and Warner Music Group accounted for nearly 70% of all revenue generated by physical and

digital music sales (Table 1). In 2019, more than half of music companies' global revenue was derived from streaming offers, only 7% from downloads and just over 20% from physical audio media. In addition to Spotify, which held a global market share of 36% in music streaming in 2019, this rapidly growing market includes Apple Music (18%), Amazon Music (13%) and the leading Chinese music platform Tencent Music Entertainment (10%), which has been linked to Spotify via a mutual equity investment since the end of 2017 [56]. The attraction of such services is the instant availability to consumers of huge catalogues of professionally produced music, either free, with adverts interrupting the music, or for a monthly subscription fee, which as well as avoiding adverts, allows offline consumption of tracks saved to devices such as laptops and mobile phones. These services provide access to many thousands of playlists, based on artists, genres, and moods, some produced by the algorithm and some by professional editors (they also allow for the creation and sharing of playlists by users). South Africa's music industry is dominated by international music companies such as Universal and Sony, which are also global industry leaders. Although South Africa's music revenue, including physical, digital, live events and podcasts, has increased steadily, 80% of music sold and consumed locally is international [57]. Revenue from physical format sales such as CDs and records has been declining as streaming has increased. In South Africa, YouTube Music held an estimated 30% of the digital music segment in 2019. Statista [57] predicted that Google Play Stores (20%), Spotify (20%), Deezer (15%), Apple Music (10%), and others (5%) would earn revenue of US$51m in 2020.

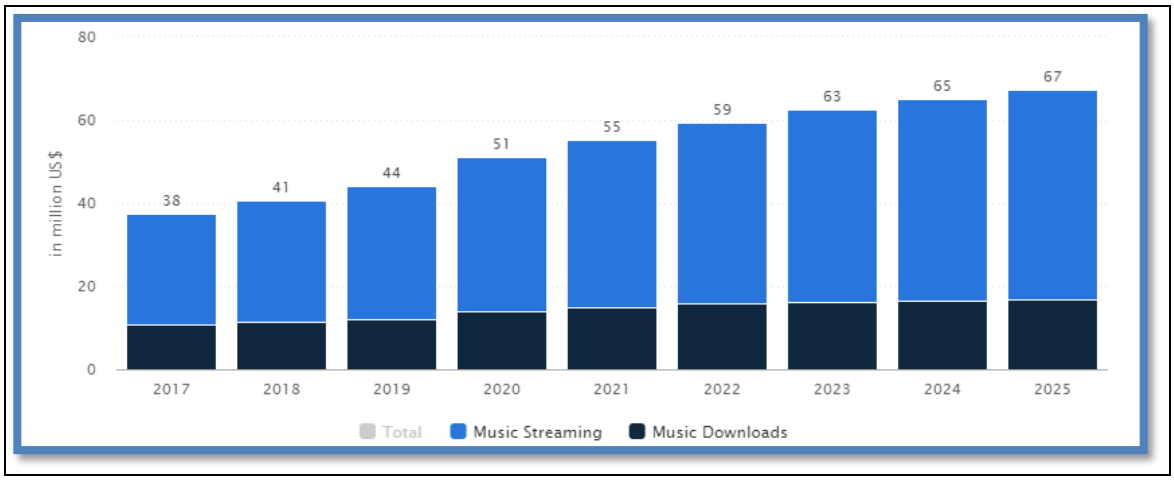

Figure 1. Forecast 2020. *Source: [57]*

Music consumption patterns arising from disruptive technological innovations and progress have influenced the (digital) music market. The disruptive impact of music streaming services like Spotify and Apple Music has overcome illegal digital music distribution while increasing access to all kinds of music genres. Firms are investing in exclusivities, such as pre-releasing new music or offering unique content such as concerts or podcasts. According to the International Federation of the Phonographic Industry (IFPI)'s Global Music Report 2019, the global recorded music market grew gradually from 2015 to 2018. It increased by 9.7 % in 2018 with total reported revenue of US$ 19.1 billion. Thirty-seven per cent of that revenue came from the 255 million users of paid streaming services [55] (Figure 1).

Methods

The study utilised an exploratory design and a quantitative research approach. Creswell [58] describes quantitative research as a method used to test theories by examining the relationships among variables. The researcher purposefully selects respondents or sites using purposive sampling based on the judgement regarding the characteristics of the representative sample. In addition to purposive sampling, snowball sampling offers a quicker and more efficient means to gather data, it was used as the additional technique to improve the return rate of the instrument. Babbie and Mouton [59] opine that this sampling strategy divulges the unknown location of the desired number of members of a special population. Snowball sampling assisted in improving the return rate, where the respondents apprise and assist in identifying the most appropriate and well-versed possible respondents. To compose, produce, record and digitally distribute music, the artist or band needs to reside in an urban area. Urban musicians mostly migrated from rural areas known for stymied music careers and circumvented the revulsion of underdevelopment. The accessibility to technology, infrastructure, and professional business configuration exhorted deluge musicians to locate in the urban areas for enterprising and wider audiences. Although the government has excoriated the urban migration explicated

by engendered by catalytic urbanisation. According to the guess estimation from Statistics South Africa [60], KwaZulu-Natal constituted a population of 3 442 361 million in South Africa, absorbing an estimation of 19.8% of the total population. Despite the scattered rural setting, 84.4% reside in urban areas. The majority of the province's population has access to "cellular phones (90.7%); while 24.6% have access to computers, 78.5% to television, 32.4% to satellite television, 71.8% to radio and 32.6% to motor vehicles" [60]. The overwhelming access allows for enhancing data collection and untangles the predicament of connectivity. Given [61] notes that "researchers who adopt a deductive or theory testing approach, select individuals or cases that embody the theoretical constructs". In this study, the assumptions of the operable theory of diffusion allow for reaching the targeted musicians in the Durban area.

Type of Sample and Sample Size

The RiSA website tentatively divulges growing 250 members affiliates in KwaZulu-Natal. The deductive reasoning applied to authenticate the identified and derived sample size resonates with the phenomenon of digitally distributed music enticing by overwhelming accessibility to technology-enabling equipment, devices and bandwidth speed. The integrated development planning in the city of Durban has flourished while parochial development in rural areas has retrograde. The antecedent plans on technological infrastructural investment created unprecedented access to the resources required to diffuse innovation and accelerate entrepreneurial practices. A target sample of 152 respondents was determined from the estimated population of 250 [62]. However, the final sample was 217, which is almost 87% of the total population, where the researchers commend the utilisation of the snowball technique for improvement from 152 to an adequate sample of 217. Purposive sampling was used to select specific subjects such as musicians/entrepreneurs/managers while snowball sampling assisted in improving the return rate through referrals. Data was gathered utilizing a questionnaire with closed-ended questions. Saunders et al. [63] describe closed-ended questions as those "where participants select responses from a limited number of given alternatives". The questionnaire is composed of a biographical section; dichotomous questions with options (Yes or No); and Interval scale or rating questions using a 5-point Likert scale from strongly disagree (1), to disagree (2), neutral (3), agree (4) and strongly agree (5). The questionnaires were administered personally and via electronic mail to Durban musicians. Personal interaction facilitated the administration of the questionnaires as the researchers were able to provide clarity when necessary.

Results and Discussion

Data analysis entails the "application of reasoning to understand the data that has been gathered" [64] and involves "breaking up the data into manageable themes, patterns, trends and relationships" [59]. The data analysis techniques were to the study's objectives. The data was captured using the Statistical Package for the Social Sciences (SPSS) while construct validation and reliability were checked for accuracy and correctness of the data. Where the constructs are measured with sufficient reliability with 22 variables on the 5-point Likert scale, the Cronbach's Alpha of the instrument is 0.826. The adequacy of the sample was further determined using the Kasier-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Accuracy. The appropriate tests using descriptive analysis and Bartlett's Test of Sphericity (1030.375) were used to verify the assumption of homogeneity of variance with a significant *p*-value of 0.000 at the 95% confidence level to be deemed appropriate.

Seventy-eight per cent of the respondents agreed that digital music distribution has added value to the growth of the South African recording industry (Figure 2), with less than 10% disagreeing with this statement. Eight-five per cent of the respondents confirmed that the Internet has enhanced digital music distribution and 61.1% agreed that the digital platform has assumed the role of record labels in managing musicians, with 30% remaining neutral on this issue. Many of the respondents (77%) opined that digital technology has improved mass consumption of online music, although 72% also concurred that this has resulted in the closure of physical music retail stores. Seventy-six per cent agreed that the Internet plays a role in both creating and promoting music entrepreneurs. Although 32% of the respondents depicted neutrality to establishing a distinction between brick-and-mortar music distribution and digital music distribution, 62% majority didn't observe the blur and confidently accentuate that digitisation supersedes the traditional approach. Finally, the Figure shows that a significant number of respondents applauded the Internet as a propulsion medium for digital music distribution.

In the city of Durban, musicians (Table 2) embraced the diffusion of the Internet platform for digital music distribution illustrated by the highest mean value (m=4.25 and std=0.84), implying that it has made a significant contribution to the massive consumption of music online (m=4.06, std =0.89). The digital distribution of music

resonated with the creating value-added in the growth of the South African recording industry (m=4.05 and std=0.9) while producing new entrepreneurs (m=4 and std=0.86). The displacement effect is evident in physical music retail stores (m=3.95 and standard deviation=0.89) where previously successful brick-and-mortar stores are closing shops. The displacement effect paradigm amongst traditional practices and digital music modelling (m=3.78 and standard deviation=0.9) has not completely removed the effect of disintermediation (m=3.75 and std=0.96), as the impetus of the Internet is deemed relatively essential in playing the role of record labels in managing musicians.

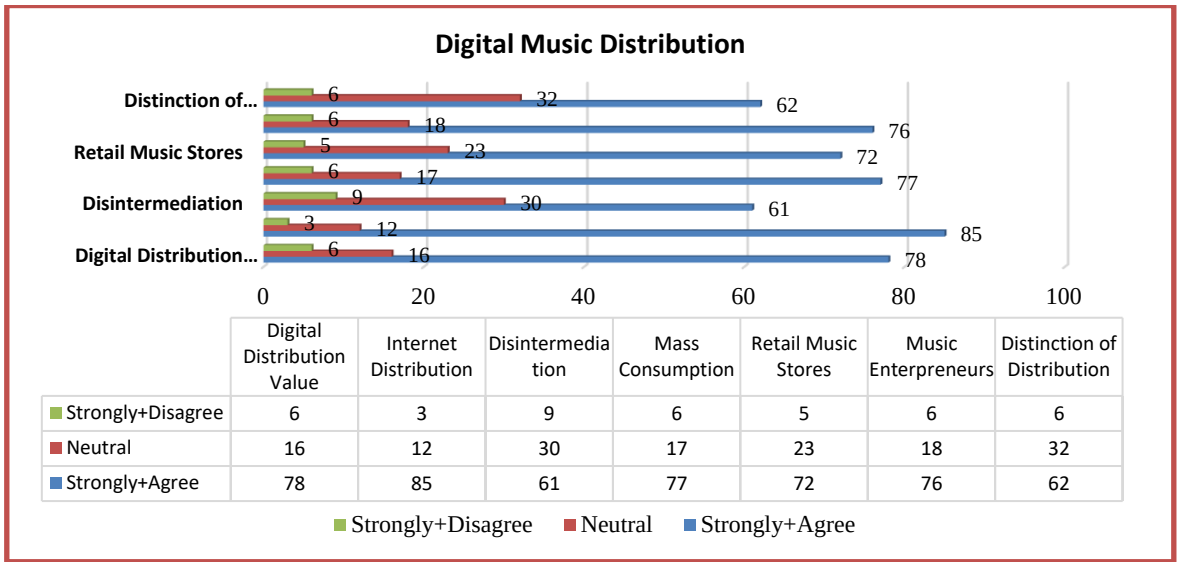

Figure 2. Analysis of Digital Music Distribution. *Source: Authors.*

Table 2. Descriptive Statistics on Music Distribution. *Source: Authors.*

	Internet distribution	Mass consumption	Digital distribution value	Music entrepreneurs	Retail music stories	Distinction of distribution	Disintermediation
N	217	217	217	217	217	217	217
Mean	4.25	4.06	4.05	4	3.95	3.78	3.75
Median	4	4	4	4	4	4	4
Mode	5	4	4	4	4	4	4
Std. deviation	0.842	0.89	0.901	0.885	0.888	0.905	0.959

Factor Analysis

Cronbach's Alpha value resonates with the level of internal consistency underpinning construct validity. The 5-point Likert scale was utilised to measure 22 variables with Cronbach's Alpha value of 0.826. According to Cooper and Schindler (2010), "acceptable alpha values range from 0.7 to 0.95" indicating good reliability. Factor analysis compresses variables to manageable factors. The adequacy of the sample was further determined using the Kasier-Meyer-Olkin (KMO) Measure of Sampling Adequacy.

The KMO score of 0.812 > 0.6 has a desirable value of sampling adequacy with a suitable level of variance (Table 3). Bartlett's Test of Sphericity (1030.375) has the assumption of homogeneity of variance that gave a significant *p*-value of 0.000 at the 95% confidence level for factor analysis to be deemed appropriate. Bartlett's test confirms there is some "level of correlation among the variables" [65] for the application of factor analysis at the degree of freedom (231) [66]. Communality refers to the amount of variance that can be explained by the common factors of a variable [63,65] ranging from 0 to 1. Table 3 shows that all items have an extraction value greater than 3; they thus fit well with the other items in their component. The factor extraction procedure determines the intention of reducing the complexity of the factors by stating the factor loading in a clearer, more understandable and interpretable manner [67,68]. According to Hatcher [68], "principle components analysis converts a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables". Garson [66] notes that the loadings of Likert scales with 0.6 may be considered "high".

An alternate way to perform factor extraction is to use Kaiser's criterion or the eigenvalues rule. Using the eigenvalues rule, only factors with a value of greater than 1.0 are retained for further investigation. By rule of thumb, any factor that has an eigenvalue of less than 1.0 does not have enough total explained variance to represent a unique factor, and is therefore disregarded [63,65]. In this analysis, components 1, 2, 3, 4, 5 and 6 have eigenvalues greater than 1 and relate to 4.94, 1.824, 1.664, 1.227, 1.105 and 1.072, respectively.

Table 3. Rotated Component Matrix. *Source: Authors.*

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.812
Bartlett's Test of Sphericity	Approx. Chi-square	1030
	Df	231
	Sig.	0.000

Rotated Component Matrix

	Factor Loading	Eigenvalue	% of Variance	Cumulative %	Communalities Extraction	Alpha
Factor 1: Digital Music Consumption Cycle						
Digital music consumption	0.668	4.94	22.454	22.454	0.515	0.635
Free online music consumption	0.633				0.495	0.646
Bandwidth speeds	0.608				0.472	0.628
Factor 2: Digital Responsiveness						
Service delivery	0.742	1.824	8.293	30.747	0.479	0.577
Clockspeed	0.605				0.469	0.568
Factor 3: Digital Music Legitimacy						
Regulation	0.722	1.664	7.594	38.31	0.577	0.662
Disintermediation	0.665				0.636	0.609
Copyright laws	0.636				0.527	0.687
Factor 4: Internet Mass Consumption Cycle						
Mass consumption	0.814	1.227	5.576	43.886	0.685	0.598
Internet distribution	0.749				0.756	0.6
Factor 5: Digital Value Adding Innovations						
Value adding innovations	0.73	1.105	5.023	48.91	0.61	0.644
Digital distribution value	0.727				0.647	0.625
Factor 6: Echelon Disintermediation						
Retail music stores	0.685	1.072	4.873	53.782	0.626	0.631

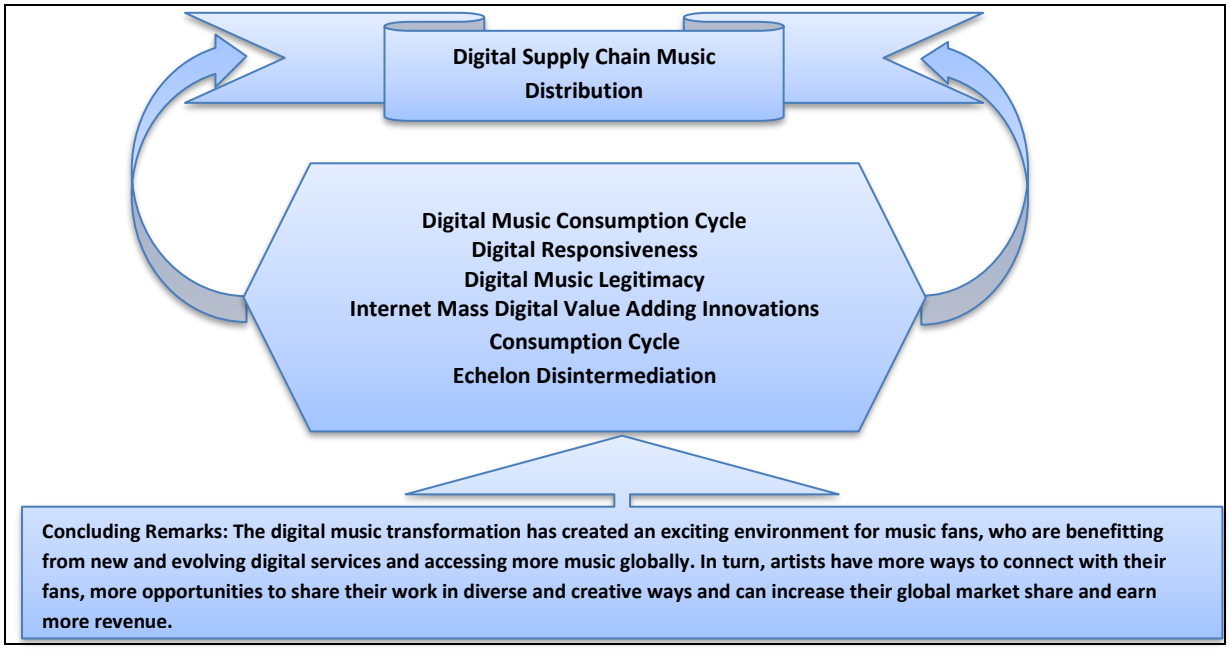

Figure 3. Digital Supply Chain Music Distribution. *Source: Authors.*

Interpretation and Labelling of Factors

Costello and Osbourne [67] state that the purpose of the rotation is "to simplify and explain the data structure". This study employed factor loadings as the basis for imputing a label to the different factors wherein the researcher examined the most highly or heavily loaded indicators in each column and assigned a factor label (Figure 3). The factor interpretations and labels are confined to the assumption of face valid imputation of factor label (face validity) that is rooted in theory.

Factor 1: The Digital Music Consumption Cycle shows the biggest variable loadings on six extracted factors. Subsequently, the loadings on Factor 1 account for 22.454% of the total variance. Digital music distribution using free online music and access to high bandwidth speed online downloads influence the digital music consumption cycle. Datta, Knox and Bronnenberg [69] found that premade playlists expand users' listening habits to a larger selection of artists, music titles and genres while decreasing their level of concentration when listening. Aguiar and Waldfogel [70] showed that music titles that appear in major playlists generate a large number of additional streams. Bandwidth accessibility invigorates fans to consume music frequently online using streaming services where musicians, businesses and Internet radio stations, to name but a few, allow consumers free access to a myriad of music genres through digitally viable medium platforms such as legal channels like iTunes, Spotify and others. Diduck [71] refers to this as "a 'try-some-buy-some' strategy which unfolds either through encouraging the jump to paid streaming services or by spurring traditional sales". Digital transformation widens accessibility to consumers, and so too are the millions of songs produced by musicians freely downloadable.

Factor 2: Digital responsiveness in Factor 2 accounts for 8.293% of the total variance. Both service delivery and clock speed enhance flexibility in the supply chain through agility. The digitalisation of music swiftly responds to consumers' dynamic demands emanating from the marketplace. The technology platforms seem to deliver both music services and products in entrenching supply chain distribution dependability and competent capability. Furthermore, with the introduction of technologies such as the IoT and 5G, the efficacy and utility of supply chain management have improved significantly [2]. Supply chain digitalisation refers to the use of modern technological advances to make logistics processes more dynamic, fast, and resilient [72]. Digitalisation optimises the supply chain by making it faster, more flexible, granular, accurate, and efficient [73]. The IoT is the most effective technology for the digitalisation of the supply chain as it enables inventories to automatically request fresh stocks based on current demand, previous data analysis, and pending stock without human involvement [72]. Big supply chain analytics uses data and quantitative tools to improve decision-making for all supply chain operations [74]. An agile supply chain system enjoys a certain level of flexibility that creates considerable resilience in responding to the disintermediation of the retail music industry. The digital environment facilitates more exposure by broadening musicians' audience base, eliminating the influence of gatekeepers, and facilitating omni-supply chain distribution through discretional social networks.

Factor 3: Digital Music Legitimacy reflects that three items load that account for 7.594% of the total variance. One item relates to disintermediation in the supply chain, while the remaining two relate to copyright laws and the regulation and closure of digital services. Disintermediation is prominent in the literature and the data. The disintermediation of the record label in the traditional supply chain resulted in the mass consumption of free online music downloaded from illegal services without paying a fee. This practice should be transformed into a legitimate business model underpinned by a centralised legal music distribution channel in the South African recording industry. Copyright challenges and regulatory barriers are limiting the capacity of digital music distributors to achieve a sustainable competitive advantage [75]. Digital distribution of music has created new opportunities for artists, enabling them to be independent of legacy labels. It has developed a new digital ecosystem [76] that allows some music artists to become successful entrepreneurs. Using the opportunities offered by new technologies, operators have been able to create and develop new business models. However, illegal copying and sharing of files continue, with streaming posing a new threat to the music industry. According to Poolsawat [77], broadband and Internet-enabled smartphones have exacerbated music piracy and loss of revenue among both music labels and their artists. Chiou, Huang, and Lee [78] describe piracy as the greatest single threat confronting the modern global music industry, while Klym [79] notes that technology has made it easier to acquire digital music illegally.

A well-designed legitimate omni-music distribution model would provide commendable protection for musicians using copyright laws. One solution would be for musicians to stream music through centralised distribution channels such as YouTube, iTunes or Spotify. Although the music will not be paid for, it will be streamed. Regulation and disclosure of various digital distribution services would reduce the illegal downloading of music.

Factor 4: The Internet Mass Consumption Cycle accounts for 5.576% of the total variance capturing fans' mass consumption of music and Internet/electronic distribution. Digital capabilities along the music industry supply chain networks of cyber-governance, lean processes, big data supply chain analytics and agile performance management require integrated technological capability [12]. Digital supply chain transformation has reflected an interplay between consistently strong technological innovation dynamics, serious socioeconomic restructuring, and substantial changes in the patterns of music consumption [80]. The IFPI [4] reported that, in 2014, streaming in the United Kingdom accounted for 12.6% of the global user market, while streaming service Spotify reached a global user community of 60 million, 15 million of whom pay for Spotify's services. There is a lack of empirical research on how streaming platforms might be influencing the structure of the industry, especially the balance of power between major and independent ('indie') record labels. Moreover, few studies have been conducted on how changes in consumption habits precipitated by streaming – such as the much-discussed shift from albums to playlists – may be influencing this balance [70].

Factor 5: Digital Value Adding Innovations account for 5.023% of the total variance, namely, value-adding innovations and digital distribution value. They are thus interpreted as "Digital value-adding innovations". Platform economics is a term used in industrial economics to analyse the activities of enterprises that distribute products online, such as streamed music. A platform coordinates distinct groups of participants in two or more markets by offering a virtual 'marketplace' where they can trade [52]. Physical retailers in South Africa need to capitalise on technology to engage their customers and achieve a competitive advantage [81]. Roux, Mahlangu, and Manetje [82] posit that "a stimulus in the retail environment (S) influences customers' organismic emotional state (O), which, in turn, leads to certain behavioural responses (R)". The digital atmospheric stimulus cues resonate with socio-digital networking that involves audience stimulus, leading to interactions and networking with other fans and musicians in the creative industry. The organism is the mediating process between the stimulus and fans' response to the virtual cues underpinned by perceptions of high enjoyment of digital hedonic value [82] for broader South African fans and artists.

Factor 6: Echelon Disintermediation accounts for 4.873% of the total variance namely, retail music stores. The Uses and Gratification (U&G) theory embodies concepts such as interactivity, demassification, hypertextuality, and asynchronicity [83]. Digital interactive music distribution rests on the notion of active fans and artists. It has been defined as "the degree to which participants (fans, artists and companies such as publishers and 3rd party) in the communication process have control over and can exchange roles as co-creators of music production, distribution and consumption cycles in their mutual discourse and value experience" [84]. Internet technology has superseded the role of record labels in espousing the modus operandi of musicians, and further extruded the number of retailing brick-and-mortar stores such as Musica and Look and Listen music stores.

Reliability and Validity

Cronbach's Alpha was used to test the reliability of the instrument for the internal consistency of the study. Its value (0.826 on 22 items) indicates the level of internal consistency by showing construct validity in terms of the interrelatedness among the items in the study without unidimensionality and homogeneity. Furthermore, the questionnaire had a high level of inter-item consistency (Cronbach's Alpha = 0.826), implying a high level of reliability. Item statistics indicate that item reliabilities ranging from 0.7 to 0.95 have acceptable Alpha values. Therefore, the researchers infer that the instrument is reliable about the dimensions of digital music distribution, namely, music distribution (0.656 on seven items), supply and demand (0.671 on nine items) and competence and capability (0.634 on six items). The dimensions of digital music distribution have strong to very high levels of reliability. The reliability statistics range from 0.634 to 0.671, indicating that the items used to measure the dimensions of the study have internal consistency and are hence reliable.

The Internet and value-adding innovations led to a transition in the distribution in the South African music industry. In response to the dichotomous questions, the overwhelming majority of the respondents (83%) stated that online retail music stores facilitate improved access to music. The revenue-driven decision looks at the mass consumption of online music (77%), although centralisation using an online distribution system through online retailers such as Spotify and iTunes have also driven accessibility. Bielas [85]; Look & Listen [86]; McIntyre [87]; Shevel [88] and Stensrud [89] opined on the displacement paradigm shift where the Internet technology diffusion augmented the massification and omnipresence in online music consumption and streaming platforms. This resulted in decreased album sales and hence less need for physical retail stores [81]. Contrarily, illegal online music massification presents another side of the coin because of plummeting physical album sales. Fuzzy

prospects of operable business seem to debilitate with supply exceeding demand of stock CDs in retail music stores. The propensity of record labels to conceal the royalties rightfully deserved by musicians while the digital distribution of music underpinned by omnichannel through Internet technology led to the disintermediation and displacement effects in the industry, namely the role of record labels. To the extent that African music sectors resemble one another, it is largely because they share a set of challenges that negatively affect music creators' ability to generate revenue from their creations [90]. These include weak networks of recorded music distribution, due to a combination of the slow adoption of digital distribution methods and the disruptive effects of digital innovations – effects that are exacerbated by the agility of unauthorised distributors or 'pirates' [90,91] – and a lack of effectiveness and transparency among collective management organisations (CMOs), which has meant that airplay (often secured through payola) does not necessarily result in royalties payments or album sales [92].

The frequency distribution and descriptive statistics produced factors relating to technological value-adding innovations and their relation to digital music distribution for music streaming, downloaded and distributed through the Internet. Platforms can estimate an individual's willingness to pay based on data acquired from users' previous sales or their profile (gender, age, and interests, among other factors) obtained from their own or other data sources [93]. Perfect (first-degree) price discrimination, which elicits the maximum revenue from consumers, is possible as well as dynamic pricing that is sensitive to the interaction between supply and demand with AI settings now widely adopted by platforms [94]. They benefit from both direct and indirect network effects as well as from scalability synergies and economies of scope [50,93]. Roux [83] notes that the focus is on "what people do with media," which involves an assortment of reactions and explanations. Gratification sought refers to the gratification that people seek and potentially receive from media use, while gratification attained refers to the satisfaction obtained by active media users [95]. Digital music distribution has added value to the growth of the South African recording industry underpinned by seventy-eight per cent from deductive statistics. The mean value of 4.05 and standard deviation of 0.9 further indicate that the respondents were in significant agreement that digital distribution has added value to the recording industry. Technologically driven demand infuses knowledgeability to expedite the flow of information for optimisation of business improvement and competitiveness.

Impact

The study analyses the extent of distribution operations processes being in sync with digital diffusion supply chain innovations and whether they impact digital music distribution and consumption in the recording industry. This digital music transformation has created an exciting impactful environment for music fans, who are benefitting from new and evolving digital services and accessing more music globally. In the multiplier impact, artists have more ways to connect with their fans, more opportunities to share their work in diverse and creative ways and can increase their global market share and earn more revenue. The impact of the phenomenon of digital music distribution evinced the epitome of scalability to digital, screaming and online music massification, consumption, platformisation, displacement and resilient economic value. The creation and promotion of innovative music entrepreneurs indicate a multiplier effect on digital transformation as it brought a scintillating trajectory with reformed daily operable business activities, including the creation of access to and consumption of music. The success of self-released albums by bands Radiohead and Nine Inch Nails, and South African musicians such as Nasty C, Zakes Batwini (bestowed with Grammy Award in 2023), and Professor (Kwaito Artist) depicts the testament for operable and predicate the perspicacity of innovative digital technologies to create independent shrewd music entrepreneurs. Furthermore, the amplitude of music downloads is proffered by modular technological developments, such as the buttress of smartphones. The impact of music m-commerce has opened a space for new forms of intermediation that have been taken up by an array of new and previously existing firms. According to De Beukelaer and Eisenberg [96], these digital content firms fall into two types, namely, digital content intermediaries and third-party m-commerce platforms. The former license music content and aggregate it for mobile service providers. In many cases, a digital content intermediary also – perhaps even primarily – operates in other areas outside of music, offering digital solutions to large corporations (including, but not limited to, mobile service providers). In this regard, the music distribution impact is entrenched by the magnitude of agility, modularity, and portability of media sharing such as Shareit, Deezer, Spotify, iTunes and so on, operable on smartphones, laptops, tablets and other devices. Digital technology-compatible devices create a cohort of innovations to achieve technological integration and competitiveness. Although the greatest impact of music distribution innovation has expanded to streaming platforms, streaming revenue depends on both sides of the market: subscriptions and fees from advertisers [49]. As markets are international, revenue is also influenced by other factors such as variations in currency rates in

the consumer's domicile and national copyright law. How much is passed on to songwriters and recording artists depends on the contract and the royalty rate negotiated with the publisher and/or the record label [50]. Arguably, economies of scale and scope can internalise benefits from network effects, spillovers and synergies that can be captured within the corporate enterprise. The music industry could therefore be swallowed up in a multi-product corporation, losing its identity and perhaps any vestigial claim to creativity [49], with the economics of streaming suggesting less rosy prospects for this industry. The crucial assessment of the potential impact of digital music distribution is the displacement paradigm of the superfluity of physical music distribution (where analogy music stores closed) and the stymieing intermediation (where innovation artists/entrepreneurs are earning revenues and royalties) from their original work.

Conclusions

New Internet technologies may compel labels that still exist to significantly alter their sales methods to consumers, as well as how they provide intermediary service to musicians. Record labels' main source of bargaining power with musicians has traditionally been their ability to offer large-scale distribution of CDs and digital technologies threaten this source of strength. A paradox about digital Internet technologies is that they simultaneously threaten to terminate record labels' distribution while having the ability to charge positive prices for a single music file that has been replicated and repeatedly sold. The Internet brings new players and business models to the South African recording industry and is becoming a vehicle that provides strength and focus on digital distribution. Technological advancements have undoubtedly changed the way organisations conduct business and the development of centralised digital distribution channels is being fast-tracked to accommodate consumption habits. In conclusion, the digital music transformation has created an exciting environment for music fans who are benefitting from new and evolving digital services and accessing more music globally. In turn, artists have more ways to connect with their fans, more opportunities to share their work in diverse and creative ways and can increase their global market share and earn more revenue. The study shows that the digital music distribution channel has added significant economic value and offers an exciting environment to music fans who benefit from streaming services that enable them to access digital music and entertainment platforms. The interconnectivity between artists and fans creates opportunities to grow the industry. If the digital market continues to grow, so too will the overall level of remuneration of artists, as well as the levels of overall investment required to create new music whilst driving digital innovation. The study covered a single region although the sample was sufficiently broad and the mobility of disc jockeys (DJs) in South Africa facilitated access to music experts. The use of snowball sampling assisted in delimiting the return rate and the administration of the questionnaire. Future research could examine the growth of music in South Africa and on the African continent. Much work is also required to advance and transform old music on records/vinyl, cassettes, and other forms into online formats for legal accessibility. Illegal remixes sparked this concern rather than a legally orchestrated plan to derive royalties for the legendary musicians of yesteryear. In South Africa, Gallo, EMI, Universal and Sony Music publishers should utilise their access to the country's largest back catalogue of music as custodians of rich heritage-based music.

Conflict of Interest

There are no conflicts to declare.

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References

[1] D.M. Weigl, K.R. Page, A framework for distributed semantic annotation of musical score: "Take it to the bridge!," in: Proc. 18th Int. Soc. Music Inf. Retr. Conf. ISMIR 2017, Suzhou, China, 2017: pp. 221–228.

[2] H. Pervez, I.U. Haq, Blockchain and IoT Based Disruption in Logistics, in: 2019 2nd Int. Conf. Commun. Comput. Digit. Syst. C-CODE 2019, 2019: pp. 276–281. https://doi.org/10.1109/C-CODE.2019.8680971.

[3] M. Sandler, D. De Roure, S. Benford, K. Page, Semantic Web Technology for New Experiences Throughout the Music Production-Consumption Chain, in: 2019 Int. Work. Multilayer Music Represent. Process., IEEE, 2019: pp. 49–55. https://doi.org/10.1109/mmrp.2019.00017.

[4] International Federation of the Phonographic Industry, IFPI Digital Music Report 2011, 2011.

[5] Risa, Risa: Recording Industry Of South Africa, (2012). http://www.risa.org.za/.

[6] G. Graham, B. Burnes, G.J. Lewis, J. Langer, The transformation of the music industry supply chain: A major label perspective, Int. J. Oper. Prod. Manag. 24 (2004) 1087–1103.

https://doi.org/10.1108/01443570410563241.
[7] N.S. Netshakhuma, Exploration role of volunteerism on the digitisation project: case of the office of the premier in Mpumalanga province, South Africa, Collect. Curation. 40 (2021) 15–23. https://doi.org/10.1108/CC-12-2019-0048.
[8] N. Skulan, Staffing with students: Digitizing campus newspapers with student volunteers at the University of Minnesota, Morris, Digit. Libr. Perspect. 34 (2018) 32–44. https://doi.org/10.1108/DLP-07-2017-0024.
[9] Jan Vermeulen, Music sales tanking in SA, Http://Mybroadband.Co.Za/. (2014). http://mybroadband.co.za/news/internet/104009-music-sales-tanking-in-sa.html.
[10] S. Knopper, Digital Music Takes a Dive as Record Sales Slip Again in 2013: Streaming services have picked up slack, but album sales in nearly all genres dipped last year., (2014).
[11] J.W. Morris, Selling Digital Music, Formatting Culture, Sell. Digit. Music. Formatting Cult. (2019). https://doi.org/10.1525/9780520962934.
[12] P. Agrawal, R. Narain, Digital supply chain management: An Overview, IOP Conf. Ser. Mater. Sci. Eng. 455 (2018) 012074. https://doi.org/10.1088/1757-899X/455/1/012074.
[13] R. Sundaram, R. Sharma, A. Shakya, Digital transformation of business models: A systematic review of impact on revenue and supply chain, Int. J. Manag. 11 (2020) 9–21. https://doi.org/10.34218/IJM.11.5.2020.002.
[14] J. Bleicher, H. Stanley, Digitization as a catalyst for business model innovation a three-step approach to facilitating economic success, J. Bus. Manag. 12 (2016) 62–71.
[15] J. Linton, Diffusion of innovations, Free Press, New York, 1998. https://doi.org/10.4337/9781800883284.diffusion.of.innovations.
[16] P. Yu, Diffusion of Innovation theory, Implement. Sci. Key Concepts. (2022) 59–61. https://doi.org/10.4324/9781003109945-16.
[17] I.L. Wu, C.H. Chuang, Analyzing contextual antecedents for the stage-based diffusion of electronic supply chain management, Electron. Commer. Res. Appl. 8 (2009) 302–314. https://doi.org/10.1016/j.elerap.2009.04.013.
[18] P.C. Lin, Y.H. Huang, The influence factors on choice behavior regarding green products based on the theory of consumption values, J. Clean. Prod. 22 (2012) 11–18. https://doi.org/10.1016/j.jclepro.2011.10.002.
[19] T.P. Mbhele, Decoupling paradigm of push-pull theory of oscillation in the FMCG industry, South African J. Bus. Manag. 47 (2016) 53–66. https://doi.org/10.4102/sajbm.v47i2.60.
[20] A. Rangaswamy, S. Gupta, Innovation adoption and diffusion in the digital environment: some research opportunities, New Prod. Diffus. Model. (2000) 75–96. http://www.ebrc.psu.edu/.
[21] H.C. Chang, A new perspective on Twitter hashtag use: Diffusion of innovation theory, Proc. ASIST Annu. Meet. 47 (2010). https://doi.org/10.1002/meet.14504701295.
[22] brahim M. Al-Jabri, M.S. Sohail, Mobile banking adoption: Application of diffusion of innovation theory, J. Electron. Commer. Res. 13 (2012) 379–391.
[23] G. Rossman, Climbing the charts: What radio airplay tells us about the diffusion of innovation, Princeton University Press, New Jersey, 2012. https://doi.org/10.1177/0094306115588487rr.
[24] S. Castellano, O. Ivanova, M. Adnane, I. Safraou, F. Schiavone, Back to the future: Adoption and diffusion of innovation in retro-industries, Eur. J. Innov. Manag. 16 (2013) 385–404. https://doi.org/10.1108/EJIM-03-2013-0025.
[25] Ö. Öz, The Competitive Advantage of Nations, The Free Press: New York, New York, USA, 2019. https://doi.org/10.4324/9780429439087-1.
[26] J. Parc, S.D. Kim, The digital transformation of the Korean music industry and the global emergence of K- op, Sustain. 12 (2020) 7790. https://doi.org/10.3390/SU12187790.
[27] P. Vonderau, The Spotify Effect: Digital Distribution and Financial Growth, Telev. New Media. 20 (2019) 3–19. https://doi.org/10.1177/1527476417741200.
[28] R. Prey, Locating Power in Platformization: Music Streaming Playlists and Curatorial Power, Soc. Media Soc. 6 (2020) 205630512093329. https://doi.org/10.1177/2056305120933291.
[29] A. Omidi, T.R. Arbatani, M.K. Saraji, E. Norouzi, Fostering Digital Music Industry by Innovative Distribution Strategies: The Case of Iran, Int. J. Acad. Res. Bus. Soc. Sci. 9 (2019). https://doi.org/10.6007/ijarbss/v9-i8/6211.
[30] B. Lund, The fourth industrial revolution, Crown Business, New York, 2021. https://doi.org/10.6017/ITAL.V40I1.13193.
[31] E. McAfee, Andrew., & Brynjolfsson, Machine, Platform, Crowd: Harnessing our Digital Future. Chapter 1: The Triple Revolution, New York, 2017.

https://books.google.com/books?hl=en&lr=&id=zh1DDQAAQBAJ&oi=fnd&pg=PT6&dq=digital+skill+digital+resourch+digital+strategi+digital+literacy+financial+inclusion+financial+performance+spiritual+culture&ots=wGgtpY2D5d&sig=txXzfdqJPSeSvrJPczihyWoCVd0%0Ahttps://w.

[32] Unpacking E-commerce, Unpacking E-Commerce. (2019). https://doi.org/10.1787/23561431-en.

[33] U. Dolata, The Digital Transformation of the Music Industry The Second Decade: From Download to Streaming, Stuttgart Univ. Stuttgart, Inst. Für Sozialwissenschaften, Abteilung Für Organ. Und Innov. 2020–04 (2020). http://www.uni-stuttgart.de/soz/oi/publikationen/.

[34] G. Hull, The Music Business and Recording Industry, Taylor & Francis, New York, 2004. https://doi.org/10.4324/9780203957745.

[35] N. Upadhyay, Demystifying blockchain: A critical analysis of challenges, applications and opportunities, Int. J. Inf. Manage. 54 (2020) 102120. https://doi.org/10.1016/j.ijinfomgt.2020.102120.

[36] R. De', N. Pandey, A. Pal, Impact of digital surge during Covid-19 pandemic: A viewpoint on research and practice, Int. J. Inf. Manage. 55 (2020) 102171. https://doi.org/10.1016/j.ijinfomgt.2020.102171.

[37] N.E.J. West, W.F. Cheong, E. Boone, N.E. Moat, Impact of the COVID-19 pandemic: A perspective from industry, Eur. Hear. Journal, Suppl. 22 (2020) P56–P59. https://doi.org/10.1093/EURHEARTJ/SUAA187.

[38] M. Kotarba, Digital transformation of business models, Found. Manag. 10 (2018) 123–142. https://doi.org/10.2478/fman-2018-0011.

[39] A. M. Chircu, Robert J. Kauffman, Strategies for Internet Middlemen in the Intermediation/Disintermediation/Reintermediation Cycle, 1999. https://doi.org/10.1080/101967899359337.

[40] N.G. Carr, 'Hypermediation: Commerce as clickstream,' Harv. Bus. Rev. January – (2000) 46–47.

[41] M.B. Sarkar, B. Butler, C. Steinfield, Intermediaries and Cybermediaries: Sarkar, Butler and Steinfield, J. Comput. Commun. 1 (1995) 0–0. https://doi.org/10.1111/j.1083-6101.1995.tb00167.x.

[42] H.S. Spilker, Digital music distribution: The sociology of online music streams, Digit. Music Distrib. Sociol. Online Music Streams. (2017) 1–208. https://doi.org/10.4324/9781315561639.

[43] K. Kribs, Popular Music as Promotion: Music and Branding in the Digital Age, Cambridge: Polity Press, 2018. https://doi.org/10.22230/cjc.2018v43n4a3400.

[44] M. Ardolino, M. Rapaccini, N. Saccani, P. Gaiardelli, G. Crespi, C. Ruggeri, The role of digital technologies for the service transformation of industrial companies, Int. J. Prod. Res. 56 (2018) 2116–2132. https://doi.org/10.1080/00207543.2017.1324224.

[45] T. Paschou, M. Rapaccini, F. Adrodegari, N. Saccani, Digital servitization in manufacturing: A systematic literature review and research agenda, Industrial Marketing Management, 2020. https://doi.org/10.1016/j.indmarman.2020.02.012.

[46] C. Kowalkowski, H. Gebauer, B. Kamp, G. Parry, Servitization and deservitization: Overview, concepts, and definitions, Ind. Mark. Manag. 60 (2017) 4–10. https://doi.org/10.1016/j.indmarman.2016.12.007.

[47] M.K. Linnenluecke, Resilience in Business and Management Research: A Review of Influential Publications and a Research Agenda, Int. J. Manag. Rev. 19 (2017) 4–30. https://doi.org/10.1111/ijmr.12076.

[48] B. Tronvoll, A. Sklyar, D. Sörhammar, C. Kowalkowski, Transformational shifts through digital servitization, Industrial Marketing Management, 2020. https://doi.org/10.1016/j.indmarman.2020.02.005.

[49] R. Towse, Dealing with digital: the economic organisation of streamed music, Media, Cult. Soc. 42 (2020) 1461–1478. https://doi.org/10.1177/0163443720919376.

[50] J. Helgeson, Capitalism without Capital, Oxford: Princeton University Press, 2015. https://doi.org/10.7208/chicago/9780226130729.003.0006.

[51] M.M. Forum, Dissecting the Digital Dollar, 2 nd, Music Managers Forum, London, 2015.

[52] P. Belleflamme, M. Peitz, The competitive impacts of exclusivity and price transparency in markets with digital platforms, Concurrences. (2020) 2–7.

[53] C. Bălan, Dave CHAFFEY, digital business and E-commerce management: Strategy, implementation and practice, Pearson, London, 2014.

[54] T. Weinberg, The New Community Rules: Marketing on the Social Web, John Wiley and Sons, Hoboken, New Jersey, 2011. https://doi.org/10.1108/dlo.2011.08125cae.002.

[55] International Federation of the Phonographic Industry, IFPI Global Music Report 2022, 2022. https://www.ifpi.org/wp-content/uploads/2022/04/IFPI_Global_Music_Report_2022-State_of_the_Industry.pdf.

[56] Statista, Music streaming and downloads, (2020).

[57] Statista, Musikstreaming.

[58] W. Creswell, Research design/ Sage, (2014).
[59] K. Wenzel, E. Babbie, The Practice of Social Research, Teach. Sociol. 22 (1994) 126. https://doi.org/10.2307/1318620.
[60] E. Data, I. Data, Statistics South Africa Statistics South Africa Statistics South Africa Statistics South Africa Statistics South Africa, (2009) 1–16.
[61] L. Given, The SAGE Encyclopedia of Qualitative Research Methods, SAGE Encycl. Qual. Res. Methods. 2 (2012) 697–698. https://doi.org/10.4135/9781412963909.
[62] U. Sekaran, R. Bougie, Research methods for business: A skill building approach, John Wiley and Sons, United Kingdom, 1993. https://doi.org/10.1016/0024-6301(93)90168-f.
[63] M.A. Saunders, P. Lewis, A. Thornhill, Research Methods for Business Students Sixth Edition Research Methods for Business Students, Pearson Education, London, 2012. www.pearson.com/uk%0Ahttps://www.amazon.com/Research-Methods-for-Business-Students/dp/1292208783/ref=sr_1_2?dchild=1&qid=1614706531&refinements=p_27%3AAdrian+Thornhill+%2F+Philip+Lewis+%2F+Mark+N.+K.+Saunders&s=books&sr=1-2&text=Adrian+Thornhill+%2F+Phili.
[64] M. J, A.K. A, Business Research Methods, South-Western, Cengage Learning, Canada, 2020. https://doi.org/10.22573/spg.020.bk/s/026.
[65] J. Pallant, A step by step guide to data analysis using SPSS, Allan and Unwin, Australia, 2011.
[66] G.D. Garson, Testing statistical assumptions: Blue Book Series, David Garson and Statistical Associates Publishing, USA, 2012. shorturl.at/AHNQ0.
[67] A.B. Costello, J.W. Osborne, Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis, 2005.
[68] L. Hatcher, A {Step-by-Step} Approach to using {{SAS}\textregistered{}} for Factor Analysis and Structural Equation Modeling, SAS Institute, USA, 1994.
[69] H. Datta, G. Knox, B.J. Bronnenberg, Changing their tune: How consumers' adoption of online streaming affects music consumption and discovery, Mark. Sci. 37 (2018) 5–21. https://doi.org/10.1287/mksc.2017.1051.
[70] L. Aguiar, J. Waldfogel, Platforms, Power, and Promotion: Evidence from Spotify Playlists*, J. Ind. Econ. 69 (2021) 653–691. https://doi.org/10.1111/joie.12263.
[71] R. Diduck, Bandwidth: Streaming might be the future, but is it an unfair economy that exploits artists?, (2015).
[72] G. Perboli, S. Musso, M. Rosano, Blockchain in Logistics and Supply Chain: A Lean Approach for Designing Real-World Use Cases, IEEE Access. 6 (2018) 62018–62028. https://doi.org/10.1109/ACCESS.2018.2875782.
[73] K. Alicke, J. Rachor, A. Seyfert, Supply chain 4.0 – the next-generation digital supply chain, (2016).
[74] K. Alicke, C. Glatzel, K. Hoberg, P. Karlsson, Big data and the supply chain: The big supply chain analytics landscape, McKinsey Co. Oper. Extranet. 1 (2016) 6. https://www.mckinsey.com/business-functions/operations/our-insights/big-data-and-the-supply-chain-the-big-supply-chain-analytics-landscape-part-1.
[75] A. Omidi, C.D. Zotto, E. Norouzi, J.M. Valero-Pastor, Media innovation strategies for sustaining competitive advantage: Evidence from music download stores in Iran, Sustain. 12 (2020) 2381. https://doi.org/10.3390/su12062381.
[76] V. Eiriz, F.P. Leite, The digital distribution of music and its impact on the business models of independent musicians, Serv. Ind. J. 37 (2017) 875–895. https://doi.org/10.1080/02642069.2017.1361935.
[77] K. Poolsawat, An Analysis of Variables Affecting Digital Music Piracy in Y-Generations | Rangsit Music Journal, Conserv. Music - Rangsit Univ. 15 (2020) 41–55. https://so06.tci-thaijo.org/index.php/rmj/article/view/236359.
[78] J.S. Chiou, C.Y. Huang, H.H. Lee, The antecedents of music piracy attitudes and intentions, J. Bus. Ethics. 57 (2005) 161–174. https://doi.org/10.1007/s10551-004-5263-6.
[79] C.K. Duffin, A. Dumbreck, Digital Music Distribution, Music Entrep. (2020) 191–214. https://doi.org/10.5040/9781472527912.ch-008.
[80] E. Jones, Book Review: Spotify Teardown: Inside the Black Box of Streaming Music, MIT Press, London, 2019. https://doi.org/10.1177/1354856519854204.
[81] D. Grewal, A.L. Roggeveen, J. Nordfält, The Future of Retailing, J. Retail. 93 (2017) 1–6. https://doi.org/10.1016/j.jretai.2016.12.008.
[82] T. Roux, S. Mahlangu, T. Manetje, Digital signage as an opportunity to enhance the mall environment: a moderated mediation model, Int. J. Retail Distrib. Manag. 48 (2020) 1099–1119.

https://doi.org/10.1108/IJRDM-10-2018-0220.
[83] T. Roux, Users' Experience of Digital Wayfinding Screens: A Uses and Gratification Perspective from South Africa, Adv. Human-Computer Interact. 2020 (2020) 1–11. https://doi.org/10.1155/2020/7636150.
[84] J.A. Avant, K. Kim, J.L. Hayes, Thirty Years of Advertising Research in Leading Communication and Marketing Journals: Learning From the Parent Disciplines, J. Curr. Issues Res. Advert. 38 (2017) 44–64. https://doi.org/10.1080/10641734.2016.1233154.
[85] I. Bielas, The Rise and Fall of Record Labels, (2013).
[86] Look & Listen, Look & Listen in Business Rescue, (2014). http://sagamer.co.za/2014/06/25/breaking-news-look-listen-in-business-rescue.
[87] C. McIntyre, Diminishing varieties of active and creative retail experience: The end of the music shop?, J. Retail. Consum. Serv. 16 (2009) 466–476. https://doi.org/10.1016/j.jretconser.2009.08.001.
[88] A. Shevel, Music fades for Look & Listen | Business Times | BDlive, Bus. Day Live. (2014). http://www.bdlive.co.za/businesstimes/2014/06/15/music-fades-for-look-listen.
[89] B. Stensrud, Thoughts on the supply chain for recorded music., 2014. (n.d.).
[90] C. De Beukelaer, Toward an 'African' take on the cultural and creative industries?, Media, Cult. Soc. 39 (2017) 582–591. https://doi.org/10.1177/0163443716664856.
[91] M. Röschenthaler, U. Diawara, Copyright Africa: How intellectual property, media and markets transform immaterial cultural goods, Copyr. Africa. (2016) 408. https://www.proquest.com/books/copyright-africa/docview/2131273139/se-2?accountid=15297.
[92] J. Street, D. Laing, S. Schroff, Regulating for creativity and cultural diversity: the case of collective management organisations and the music industry, Int. J. Cult. Policy. 24 (2018) 368–386. https://doi.org/10.1080/10286632.2016.1178733.
[93] M. Bourreau, M. Acache, Platforms, in: N.T. Towse R. (Ed.), A Handb. Cult. Econ., 3rd ed., Edward Elgar Publishing, 2020: pp. 421–429.
[94] R. Osborne, One directive? Equitable remuneration and the making available right, (2019).
[95] S. Kutnicki, Wayfinding media and neutralizing control at the shopping mall, Crit. Stud. Media Commun. 35 (2018) 401–419. https://doi.org/10.1080/15295036.2018.1490024.
[96] C. De Beukelaer, A.J. Eisenberg, Mobilising African music: how mobile telecommunications and technology firms are transforming African music sectors, J. African Cult. Stud. 32 (2020) 195–211. https://doi.org/10.1080/13696815.2018.1546569.

POSTHARVEST TREATMENTS INFLUENCED THE INCIDENCE OF INTERNAL BROWNING, PHENOL, ABA, AND GA_3 CONTENTS OF TWO PINEAPPLE CLONES

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Highlight
Pineapple postharvest treatments on IB incidence and hormones.

Abstract
Phenol is an internal browning (IB) enzymatic reaction substrate and endogenous abscisic acid (ABA) used to suppress IB incidence in the Comte de Paris cultivar (Queen type). There is no information on the correlation between pineapple IB to endogenous total phenol content (TPC), ABA, and gibberellic acid 3 (GA_3) after postharvest applications of decrowning. Therefore, this research aimed to analyze the relationship of IB incidence to total TPC, ABA, and GA_3 after postharvest treatments of decrowning and coating in GP3 and MD2 pineapple clones. The structure was based on a completely randomized design with 3 factors, namely clone (GP3 and MD2), decrowning (crown and crownless), and coating [50 mg L^{-1} ABA, 1% chitosan, ABA+Chitosan mixture, and control (H_2O)]. The results showed that the MD2 had a lower IB incidence and higher TPC than the GP3 stored at 7°C for 37 days. The increased TPC was positively correlated with IB incidence. TPC was also negatively correlated with ABA but positively with endogenous GA_3 2 weeks earlier. Coating with 50 mg L^{-1} ABA and 1% chitosan on MD2 decreased IB incidence. Pineapple crown pruning decreased ABA and increased TPC, GA_3, and IB incidence.

Keywords
Crown pruning; chitosan; coating; cold storage; fruit; physiological disorder.

Introduction
Decreased fruit quality due to internal browning (IB) is a post-harvest problem for pineapple. Cold storage at 7–12°C extends the shelf life of pineapple fruit [1–3], but long-term storage induces fruit IB before the rots (senescence). Meanwhile, IB is an enzyme reaction that uses phenol as a substrate. In the Comte de Paris cultivar (Queen type), endogenous ABA inhibited IB incidence. The relationship between endogenous total phenol content (TPC), ABA, gibberellic acid 3 (GA_3) contents as well as IB of pineapple after postharvest applications of ABA coating and decrowning in the hybrid and Smooth Cayenne groups is unknown.

Coatings with chitosan extended the shelf life of guava [4], banana [5,6], tomato [7], strawberry [8], and avocado [9] by decreasing respiration rate. According to [10], the combined application of 200 mg L^{-1} exogenous ABA with

a storage temperature of 5°C was able to suppress the incidence of IB and GA. Spraying Queen pineapple fruit with 380 µM ABA solution was positively correlated with suppressing the incidence of IB and decreasing GA content after 9 days of storage and PPO enzyme activity after 6 days [11].

Crown pruning of queen-type pineapple was reported to increase the incidence of IB, total phenolics, and endogenous GA, but decreased endogenous ABA and ascorbic acid (AsA) [12]. This process did not affect the AsA content but had a different response to the severity of IB in pineapple clone [13]. Pineapple crown pruning in the GP3 clone increased the severity of IB but did not affect the MD2 clone.

The GP3 clone pineapple is a Smooth Cayenne type with slightly thorny leaves and a relatively sweet taste. Meanwhile, MD2 is a hybrid type, which has 50% of the same characteristics as the Smooth Cayenne cultivar. The MD2 clone pineapple has an attractive skin color and ripe fruit (golden yellow), higher vitamin C and soluble solid content, and is resistant to cold storage compared to other cultivars [14]. Therefore, it was necessary to conduct additional observations on the incidence of IB, phenol, ABA, and GA_3 content in GP3 and MD2 pineapple clones. This should be achieved after postharvest application of decrowning and coating with 50 mg L^{-1} ABA as well as 1% chitosan to determine the correlation. The severity of IB as stated by [13] was different from the incidence in this research. The severity of IB is the intensity of the brown surface area of fruit, while the incidence is the number of pineapples induced by IB without looking at the intensity. This research was expected to answer the phenomenon of the relationship between variables in GP3 and MD2 pineapple clones regarding damage due to IB.

Methods

This research used pineapples harvested from Great Giant Food Co. Ltd. with a typical export maturity level of 0% and a weight of 825 - 1124 g. The experimental design included three treatment factors, namely clone (GP3 and MD2); decrowning (crown and crownless); coating [1% chitosan; 50 mg L^{-1} abscisic acid (ABA; Phytotechlab, Kansas, USA); ABA+chitosan mixture; and control (H_2O)]. Fruit coating treatments with chitosan and H_2O were carried out by quickly dipping fruit. Coating treatments with ABA and ABA+chitosan was carried out by spraying fruit. All treated pineapples were dried for 30 minutes before being packaged in perforated GGF cardboard boxes with a capacity of 10–11 per box, and fruit was stored at 7°C for 37 days. Observations on the incidence of IB, TPC, ABA, and GA_3 were carried out 7 times (days 3, 6, 9, 16, 23, 30, and 37) for three fruits each and were repeated for a total of 336.

The incidence of IB

The incidence of IB was observed and calculated by dividing fruit into two parts from the base to the tip. This was calculated based on the percentage of fruit that triggered IB from the total fruit sample.

TPC

- Sample preparation and extraction**:** Sample preparation and extraction were carried out according to [15] with a slight extraction modification. Approximately 1 ml of pineapple juice was dissolved in 19 ml of 80% methanol using a magnetic hot stirrer at 35°C for 90 minutes.

- TPC Testing: Gallic acid solution with a concentration of 100; 150; 200; 250; and 300 ppm dissolved in methanol/water solution (1/1). About 0.1 ml each of standard gallic acid and pineapple juice extract was dissolved in 7.9 ml of distilled water. Subsequently, 0.5 ml of Folin-Ciocalteu was added to the extract solution and was allowed to stand for 8 minutes after homogenizing by shaking. The extract solution was mixed with 1.5 ml of 20% Na_2CO_3, homogenized, and left in a dark place for 120 minutes. The total amount of phenolic compounds was measured using a UV-vis spectrophotometer calibrated at 766 nm and the absorption value was calculated as mg GAE/100 ml juice.

ABA and GA_3

- Sample preparation and extraction: Frozen pineapple juice samples surrounded by ice gel were packaged and sent to the Plant Physiology Laboratory, Gadjah Mada University, Yogyakarta, Indonesia within 18 hours. Pineapple juice of 10 ml was dissolved in methanol for 24 hours, while the solution was filtered and diluted by adding distilled water to the 10 ml solution. HCl was added to the solution until the pH was 2.5 and was partitioned with 60 ml of ethyl acetate. Furthermore, the ethyl acetate phase was partitioned with 60 ml of 5% $NaHCO_3$. The phase was collected in a beaker and evaporated to dryness. The results of the evaporation were dissolved in 2 ml of pure methanol and filtered

using a microfilter [16].

- ABA compound testing: ABA compounds were detected with a Shimadzu CBM 20 A HPLC system controller, LC 20AT solvent delivery unit, CTO 10 ASVP column oven, and Shimadzu SPD 20-A UV-Vis Detector. The column (Shim-pack VP ODS 5 µm 150 x 4.6 mm) was operated at a temperature of 25°C. Additionally, the mobile phase adopted was acetonitrile / H_3PO_4 0.1% (45/55; v/v) using the isocratic method and flowed at 0.6 ml/minute. ABA standard solution of 50 µl contained 0; 0.1; 0.5; 1.0; 2.5; and 5.0 ng/ml and 0.1 ml samples were injected. The eluting compound was detected at 260 nm with a retention time of 21.015 minutes (standard R2 ABA = 0.99860).

- GA_3 compound testing: GA_3 compound was obtained with a Shimadzu CBM 20 A HPLC system controller, LC 20AT solvent delivery unit, CTO 10 ASVP Shimadzu SPD M20-A Photo Diode Array Detector column oven. The column (Shim-pack VP ODS 5 µm 150 x 4.6 mm) was operated at a temperature of 30°C. The mobile phase adopted was 25% acetonitrile using the isocratic method and flowed at 0.8 ml/minute. Furthermore, 50 µl GA_3 standard solution was reported to contain 0.1; 1.0; 5.0; and 25.0 ng/ml, and 0.1 ml samples were injected. The eluting compound was detected at 206 nm with a retention time of 12.316 minutes (standard R2 GA_3 = 0.98000).

Statistical analysis

Research data were analyzed through the 95% mean ± confidence interval (CI) method (α = 0.05) with analysis of variance (ANOVA) using IBM-SPSS version 26 program.

Results and discussion

Responses of pineapple clone

IB was not detected after a shelf life of 16 days and only appeared on the 23rd day (Figure 1.A). This was supported by previous research that the incidence of IB in the cultivars Pattavia, GP3 (Cayenne type), and MD2 was not detected after a shelf life of 14 days in cold storage [17]. According to [18], IB incidence did not appear on the 21st day in the Pattvia pineapple cultivar (Smooth Cayenne type) which was stored at 25°C.

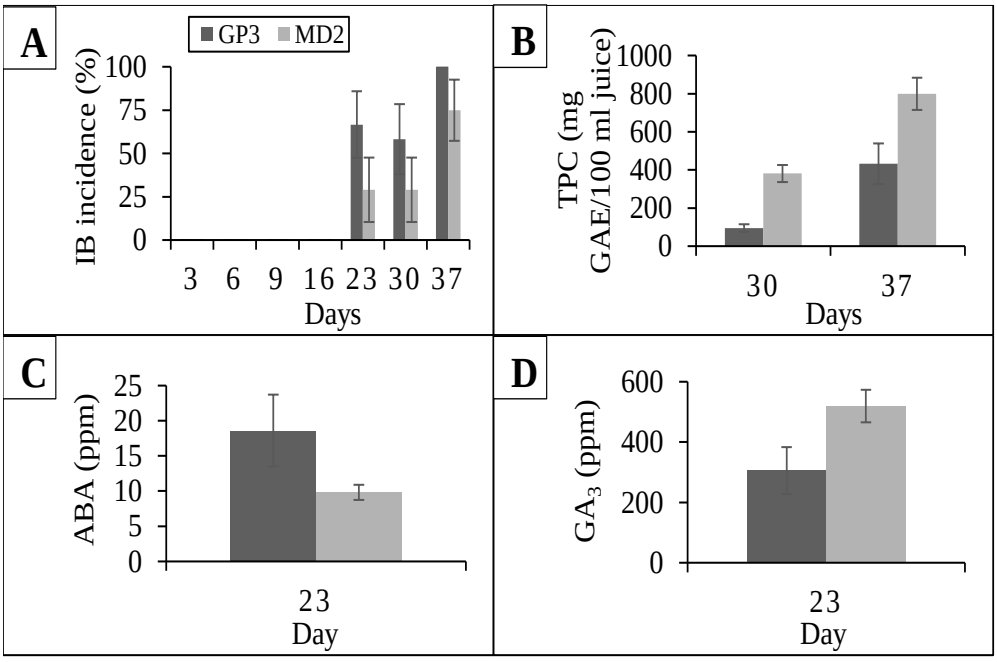

Figure 1. Responses of pineapple clone to IB incidence, TPC, ABA, and GA_3 after being stored at 7°C for 37 days.
Source: Author.

The incidence of IB in the GP3 pineapple clone (Smooth Cayenne type) was higher than in the MD2 (hybrid type), as shown in Figure 1.A. These results were also supported by several other research, where the MD2 cultivar had quite high resistance to IB [17,19,20]. According to [17], the sclerenchyma observed using scanning electron

microscopy (SEM), had a thicker fiber layer structure and was larger than the susceptible cultivars Trad-see-thong and Pattavia (tolerant). In addition, MD2 sclerenchyma cells formed concentric rings around the phloem and xylem. In line with [13], the AsA content in the MD2 clone was higher than in the GP3 clone. The high content increased the reaction with ROS to prevent cell degradation, and AsA inactivated the enzyme polyphenol oxidase (PPO).

TPC of the MD2 pineapple clone which was higher than GP3 clone (Figure 1.B) did not correlate with the incidence of IB (Figure 1.A), where TPC is directly proportional to the incidence of IB. The relationship between AsA and TPC in increasing the incidence of IB was also explained by [21]. The high content of AsA suppressed the incidence of IB in pineapple, even though TPC was relatively high. The genotype influences the antioxidant pathway and when the product shows significant resistance, increased activation occurs in response to stress [22]. According to [2], pineapple genetics influences fruit resistance to IB, and three types of pineapple were stored at 4 ± 2 °C for 28 days. The incidence of IB was correlated with AsA. The highest AsA content was possessed by MD2 followed by Moris and Josapin on day 28. TPC of the three types of pineapple was similar. The AsA content and IB incidence were inversely related, with MD2 having the lowest result. According to [12], an increase in the incidence of IB was correlated with TPC in Queen pineapple. IB incidence is a complex reaction that does not only consider TPC but is related to the amount or activity of the PPO enzyme. In line with [13], the MD2 clone pineapple had an AsA content than the GP3 clone. This suppresses the incidence of IB through the antioxidant activity of AsA, and high TPC did not affect the incidence of IB.

The increase in IB incidence in pineapple clone GP3 and MD2 from day 30 to 37 was positively correlated with high TPC. According to [13], the AsA content of pineapple stored at 7°C on day 30 was not significant compared to day 37. This caused TPC to play an important role in increasing the incidence of IB. Phenolic compounds were substrates for enzymatic browning reactions catalyzed by PPO in the synthesis of o-quinone. Furthermore, the o- uinone polymerizes or reacts with other phenolic compounds to form melanin which causes browning [10,23,24]. The decrease in the incidence of IB was positively correlated with the activity of phenolic enzymes and phenylalanine amino-lyase (PAL) from days 6 to 12 in Queen pineapple. In a study conducted by [17], pineapple flesh close to fruit core (F/C) contains higher levels of phenolic compounds, followed by PPO and peroxidase (POD) enzyme activity compared to healthy fruit. An increase in TPC occurs with the shelf life of pineapple fruit (Figure 1.B). These results are also supported by [25], where phenolic levels had a greater influence on maturity than the incidence of IB. Therefore, the coated fruit also experienced an increase in phenolic compounds and was lower than the control. This means that a greater amount of IB substrate creates a high possibility of enzymatic browning reactions.

The GP3 pineapple clone on day 23 had a higher ABA content (Figure 1.C) and lower GA_3 (Figure 1.D) compared to MD2. Based on the results of [18], there was no correlation between the endogenous ABA content and the incidence of IB in the Trad-see-thong and Pattavia pineapple cultivars. The development of the endogenous ABA content tended to fluctuate from day 0 to 21. According to [10], ABA and GA content had a negative and positive correlation with the incidence of IB. In a study conducted by [13], the resistance of the MD2 pineapple clone to the severity of IB was positively correlated with the AsA content. Based on the results, the endogenous ABA and GA_3 values in initiating IB incidence depended on the AsA content values of pineapple cultivars.

Pineapple crown pruning effect

Crown pruning of MD2 pineapple insignificantly increased the incidence of IB (Figure 2.A) and TPC on day 37 (Figure 2.B). This process also decreased and increased endogenous ABA and GA_3 in MD2 pineapple clone on day 23 (Figures 2. C and D). The increase in TPC in declining pineapple was supported by [12], where crown pruning of queen-type pineapple was stored at 20°C after 9 days. Pineapple crown pruning also results in wounds, leading to elevated levels of O_2^-, H_2O_2, and malondialdehyde (MDA). This induces cell membrane damage by amplifying the accumulation of reactive oxygen species (ROS) and upregulating the expression and activity of PPO as well as PAL enzyme to initiate an escalation in the incidence of IB. According to [13], crown pruning of GP3 increases the severity of IB due to the high AsA in MD2 as an antioxidant in capturing free radicals.

The response of crown pruning in GP3 and MD2 pineapples to IB incidence was not similar to Queen pineapple in increasing IB incidence [12], even though there are similarities in higher phenolic compounds and GA_3. This was also supported by [18] stating that Queen type pineapple has lower resistance to IB damage than the Smooth Cayenne type with lower resistance to IB than the MD2 cultivar [20]. According to [13], pineapple pruning only

affected the severity of IB in the GP3 clone. This was associated with the high AsA content in the MD2 clone, decreasing the incidence and severity of IB, while the GP3 clone had a lower content than MD2. However, crown pruning decreased endogenous ABA and increased total phenolic compounds and endogenous GA_3. This phenomenon strengthens the information that fruit crown was a source of endogenous ABA in pineapple, but IB damage depended on other variables.

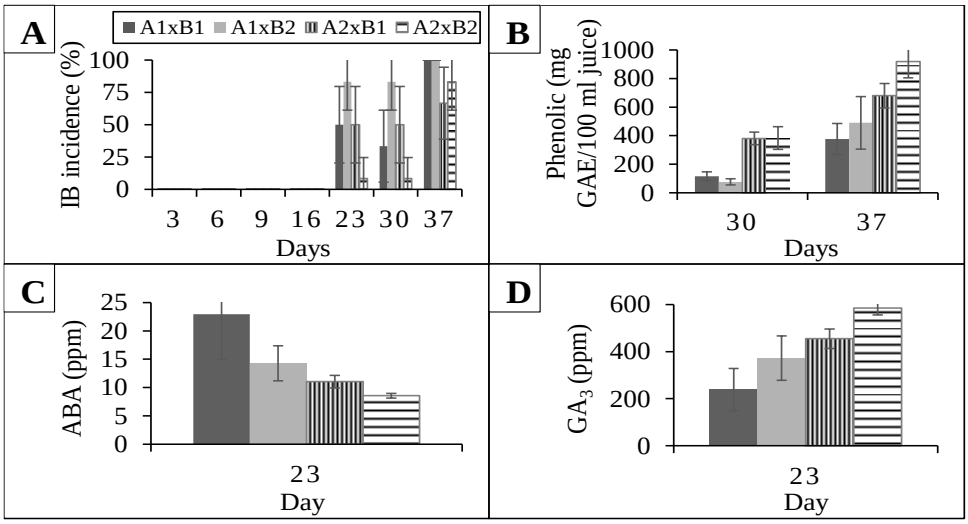

Figure 2. Effect of clone [GP3 (A1) and MD2 (A2)] and decrowning [crown (B1) and crownless (B2)] interactions on the incidence of IB, TPC, ABA, and GA_3 after being stored at 7°C for 37 days. *Source: Author.*

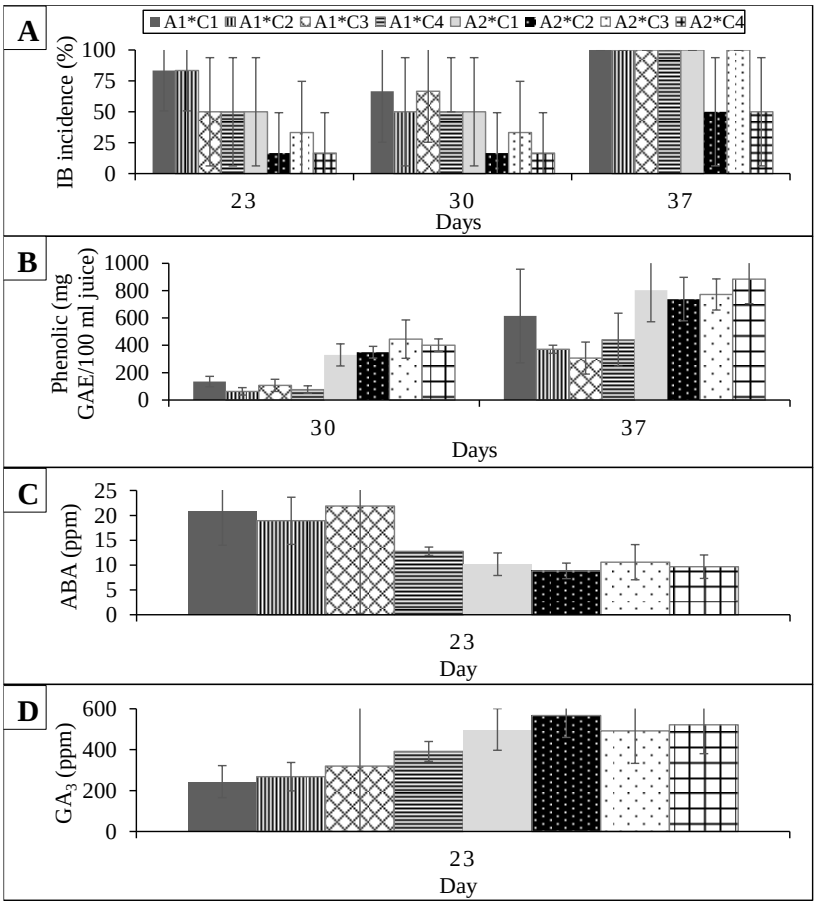

Figure 3. Effect of clone [GP3 (A1) and MD2 (A2)] and coating [H_2O (C1); 1% chitosan (C2); ABA+chitosan mix (C3); and 50 mg L^{-1} ABA (C4)] interactions on the incidence of IB, TPC, ABA and GA_3 after being stored at 7°C for 37 days. *Source: Author.*

Pineapple coating application effect

Coating with 1% and 50 mg chitosanL - 1 ABA in the MD2 pineapple clone suppressed IB incidence on the 37th day after being stored at 7°C. Therefore, the MD2 pineapple clone coated with 1% chitosan or 50 mg L^{-1} ABA suppressed the incidence of IB. Coating treatments did not affect total phenol, ABA, and GA_3 contents. Suppression of the incidence of IB in coating treatments with chitosan suppressed the entry of oxygen, hence the environment became less aerobic for phenolic oxidation. According to [26], coating fruit with chitosan suppressed browning, and PPO activity, and decreased the weight of longan fruit. The respiration rate in guava, banana, tomato, strawberry, and avocado was also suppressed [4–9]. Meanwhile, coating pineapple with ABA did not understand the inhibitory mechanism against IB. A similar result was stated by [12] that the mechanism for inhibiting the incidence of IB by ABA was unknown and required further research.

Impact

The fresh pineapple fruit industry prefers a product stored for a long time to maintain stock and delivery which requires a long time. Decrowning fruit can save packaging and storage space, but pruning increases TPC as a substrate for the browning reaction. Therefore, fruit requiring storage of up to 16-30 days must maintain pineapple crown intact. For the storage requirements of 37 days, additional post-harvest applications of 50 mg L^{-1} ABA or 1% chitosan are required.

Conclusions

In conclusion, GP3 and MD2 pineapple clones were reported to have different tolerances to endogenous TPC, ABA, and GA_3 contents which influenced the incidence of IB. The GP3 pineapple clone had a higher incidence of IB than MD2 on day 37. This was related to the large ascorbic acid content in the MD2 pineapple clone. An increase in TPC from a shelf life of 30 to 37 was positively correlated with an increase in the incidence of IB. Furthermore, postharvest coating application with 50 mg L^{-1} ABA and 1% chitosan reduced the incidence of IB. Crown pruning decreased ABA and increased TPC and GA_3 endogenous, as well as the incidence of IB.

Conflict of interest

There are no conflicts to declare.

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References

[1] R.E. Paull, Pineapple and papaya, in: Biochem. Fruit Ripening, Springer Netherlands, Dordrecht, 1993: pp. 291–323. https://doi.org/10.1007/978-94-011-1584-1_10.

[2] N.H. Dolhaji, I.I. Muhamad, H. Ya'akub, A. Abd Aziz, Evaluation of chilling injury and internal browning condition on quality attributes, phenolic content, and antioxidant capacity during sub-optimal cold storage of malaysian cultivar pineapples, Malaysian J. Fundam. Appl. Sci. 14 (2019) 456–461. https://doi.org/10.11113/mjfas.v14n4.1072.

[3] M. Mohd Ali, N. Hashim, S. Abd Aziz, O. Lasekan, Shelf life prediction and kinetics of quality changes in pineapple (ananas comosus) varieties at different storage temperatures, Horticulturae. 8 (2022) 992. https://doi.org/10.3390/horticulturae8110992.

[4] S.E. Widodo, Zulferiyenni, R. Arista, Coating effect of chitosan and plastic wrapping on the shelf life and qualities of guava cv Mutiara' and 'Crystal,' J. Int. Soc. Southeast Asian Agric. Sci. 19 (12013).

[5] M.J. Changsiriporn, M. Jitprakong, Effects of chitosan coating on postharvest quality and shelf life of banana fruit, in: TIChE Int Conf. 2011 Songkhla Thail., 2011: pp. 355–358.

[6] M.N.B. Ali, N.A. Hamid, The Effect of chitosan coating on post-harvest quality of banana in cold storage, ESTEEM Acad. J. 17 (2021) 85–92.

[7] A.E. Ghaouth, R. Ponnampalam, F. Castaigne, J. Arul, Chitosan coating to extend the storage life of

tomatoes, HortScience. 27 (1992) 1016–1018. https://doi.org/10.21273/HORTSCI.27.9.1016.

[8] M. Vargas, A. Albors, A. Chiralt, C. González-Martínez, Quality of cold-stored strawberries as affected by chitosan–oleic acid edible coatings, Postharvest Biol. Technol. 41 (2006) 164–171. https://doi.org/10.1016/j.postharvbio.2006.03.016.

[9] N. Maftoonazad, H.S. Ramaswamy, Postharvest shelf-life extension of avocados using methyl cellulose-based coating, LWT - Food Sci. Technol. 38 (2005) 617–624. https://doi.org/10.1016/j.lwt.2004.08.007.

[10] Q. Zhang, Y. Liu, C. He, S.. Zhu, Postharvest exogenous application of abscisic acid reduces internal browning in pineapple, J. Agric. Food Chem. 63 (2015) 5313–5320. https://doi.org/10.1021/jf506279x.

[11] Q. Zhang, X. Rao, L. Zhang, C. He, F. Yang, S. Zhu, Mechanism of internal browning of pineapple: The role of gibberellins catabolism gene (AcGA2ox) and GAs, Sci. Rep. 6 (2016) 33344. https://doi.org/10.1038/srep33344.

[12] J. Liu, C. He, F. Shen, K. Zhang, S. Zhu, The crown plays an important role in maintaining quality of harvested pineapple, Postharvest Biol. Technol. 124 (2017) 18–24. https://doi.org/10.1016/j.postharvbio.2016.09.007.

[13] D. Chandra, S.E. Widodo, M. Kamal, S. Waluyo, Pineapple responses to postharvest applications of ABA, chitosan, and decrowning on the severity of internal browning and other fruit qualities, Acta Innov. (2023) 64–72. https://doi.org/10.32933/ActaInnovations.47.6.

[14] A.A. Thalip, P.S. Tong, C. Ng, "Super Sweet" pineapple (Ananas comosus), UTAR Agric. Sci. J. 1 (2015) 14–17.

[15] A.A. Rasheed, L. Cobham, M. Zeighami, S.P. Ong, Extraction of phenolic compounds from pineapple fruit, in: 2nd Int. Symp. Process. Dry. Foods, Veg. Fruits Univ. Nottingham, Malaysia Campus 18th – 19th June 2012, 2012.

[16] M. Kelen, E.C. Demiralay, S. Sen, G. Ozkan, Separation of Abscisic Acid, Indole-3-Acetic Acid, Gibberellic Acid in 99 R (Vitis berlandieri x Vitis rupestris) and Rose Oil (Rosa damascena Mill.) by Reversed Phase Liquid Chromatography, Turkish J. Chem. 28 (2004) 603–610.

[17] K. Luengwilai, D.M. Beckles, J. Siriphanich, Postharvest internal browning of pineapple fruit originates at the phloem, J. Plant Physiol. 202 (2016) 121–133. https://doi.org/10.1016/j.jplph.2016.07.011.

[18] I. Pusittigul, S. Kondo, J. Siriphanich, Internal browning of pineapple (Ananas comosus L.) fruit and endogenous concentrations of abscisic acid and gibberellins during low temperature storage, Sci. Hortic. (Amsterdam). 146 (2012) 45–51. https://doi.org/10.1016/j.scienta.2012.08.008.

[19] A.A. Thalip, A.S. Thong, N. Casey, The MD2 'super sweet' pineapple (Ananas comosus), Utar Agric. Sci. J. 14 (2015) 14–17.

[20] C. Souleymane, Y.S.E. Salomé, N.A. Laurent, K.O.K. Samuel, T.H. Kouakou, Effects of potassium fertilization for pineapple on internal browning of fruit in post-harvest conservation, J. Agric. Crop. (2019) 100–108. https://doi.org/10.32861/jac.56.100.108.

[21] L.E. Ayon-Reyna, L.G. Ayon-Reyna, M.E. Lopez-Lopez, . Lopez- Angulo, K. V. Pineda -Hidalgo, J.A. Zazueta-Niebla, M.O. Vega_Gracia, Changes in ascorbic acid and total phenolics contents associated with browning inhibition of pineapple slices, Food Sci. Technol. 39 (2019) 531–537. https://doi.org/10.1590/fst.21117.

[22] P. Prajapat, D. Singh, S. Tripath, K. Patel, H. Abbas, A. Patel, Effect of water stres on antioxidative enzymes and gylicine betaine content in drought tolerant and drought susceptible cotton (Gossypium hirsutum L.) genotypes, Indian J. Biochem. Biophys. 55 (2018) 198–204.

[23] A. Concellon, M. Anon, A. Chaves, Effect of chilling on ethylene production in eggplant fruit, Food Chem. 92 (2005) 63–69. https://doi.org/10.1016/j.foodchem.2004.04.048.

[24] O. Nukuntornprakit, K. Chanjirakul, W.G. van Doorn, J. Siriphanich, Chilling injury in pineapple fruit: Fatty acid composition and antioxidant metabolism, Postharvest Biol. Technol. 99 (2015) 20–26. https://doi.org/10.1016/j.postharvbio.2014.07.010.

[25] J.M. Dahler, S.J. Underhill, Y. Zhou, J.E. Giles, Biochemical changes associated with chilling in pineapple fruit, Acta Hortic. (2002) 603–610. https://doi.org/10.17660/ActaHortic.2002.575.71.

[26] Y. Jiang, Y. Li, Effects of chitosan coating on postharvest life and quality of longan fruit, Food Chem. 73 (2001) 139–143. https://doi.org/10.1016/S0308-8146(00)00246-6.

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