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THE DEVELOPMENT FOR COEFFICENT INEQUALITY USING ANY SUBCLASS IN UNIVALENT FUNCTION: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Complex analysis involves studying the properties of complex number function. Geometric function theory is one of the fields for the complex analysis. A new generalized subclass of function is often implemented, and its characteristics are frequently discovered by researchers. However. With limited research and insufficient references, researchers find it challenging to generalize the subclasses of analytical functions that are currently in existence. The aim of this study was to determine the coefficient inequality using any subclass in a univalent function by carrying out a systematic literature review (SLR) using the PRISMA model. As SLR was done on articles obtained from these databases, data search was carried out using criteria developed from research using several search engines, including Google Scholar, Springer Link, Hindawi, Research Gate, and others. A total of 50 article were found, 25 of which were relevant to the objective of this work. Only 15 of the 25 article were relevant to the study. The results identified three major research themes, including the purpose of the study, type of subclass and properties. These results will probably serve as a framework for researchers, mathematicians, and university students to come up with a set of properties for determining coefficient inequality. The results of SLR opened a discussion on significant future study areas by identifying the main contributions, opportunities, and gaps in the discipline.

Keywords: *Univalent Function, Hankel Determinant, Coefficient Inequality, Upper bound*

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1. Introduction

The objectives of this paper are to review, analyze and classify the existing work of literature which is related to Coefficient Inequality using any subclass in univalent function. The purpose of this study is to analyze, evaluate, and organize the information that has been published by previous authors on coefficient inequality using any subclass of a univalent function.

This SLR analyses research patterns and identifies similarities. Purpose of the study, type of subclass, and properties in the research. Table 1 shows the themes of this study.

Table 1**:** Themes of this study

No	Themes of This Study
1	Purpose of studies
2	Type of subclass used
3	Properties has been used

The area of mathematics known as complex analysis is both graceful and outstanding while also being very complicated. Complex analysis is a field of research focused on complex numbers and complex-valued functions that have been developed by many eminent mathematicians. The main field of Complex Analysis is Geometric Functions Theory (GFT), involving both multivalent and univalent functions. This function is crucial to the growth of Complex Analysis. Numerous applications of geometric function theory (GFT) can be found in mathematical physics. Univalent functions are analytic functions of a complex variable that are one-to-one on a given region (that is, they take no value more than once; hence the name). They usually appear in a normalized form on the unit circle (Thomas et., 2018):

$$f(z) = z + \sum_{n=2}^{\infty} a_n z^n \,, where\ z\ \in\ E \tag{1}$$

Therefore, the univalent function is a holomorphic function $f(z)$of the form (1) in E with the assumption that f has one value in E. According to Goodman (1977) we can assume that the domain for the function in ε is schlicht or simple if function $f(z)$ is univalent in z.

Mathematicians evaluated the necessary conditions for univalence in the 1990s and attempted to prove the coefficient conjecture for the function $f \in S$ of the form (1). As a result, they introduced several subclasses that belong to S. However, Robertson already introduced two subclass which is S^* and C of Starlike and Convex functions in 1936. The class K of close-t0-convex function was introduced by Kaplan in !952. They are analytically defined:

Definition 1 (Robertson, 1936). A function $f \in S$ given by (1) is belong to the class S^* in E if only if :

$$\Re\left(\frac{zf'(z)}{f(z)}\right) > 0\,, \quad where\ z\ \in\ E$$

Definition 2 (Robertson, 1936). A function $f \in S$ given by (1) is belong to the class C in E if only if $f'(0) \neq 0$ and

$$\Re\left(1 + \frac{zf''(z)}{f'(z)}\right) > 0\,, \quad where\ z\ \in\ E$$

Definition 3 (Kaplan, 1952). A function $f \in S$ given by (1) is belong to the class K in E if only if there exist a starlike function $g\ \in\ S^*$ such that

$$\Re\left(\frac{zf'(z)}{g(z)}\right) > 0\,, \quad where\, z\, \in\, E$$

The function of $g(z)$ in Definition 1.3 is a starlike function in the open unit disk E satisfying the inequality in Definition 1.1 and has the form:

$$g(z) = z + \sum_{n=2}^{\infty} b_n z^n,\ where\ z\, \in\, E \qquad (2)$$

2. Literature Review

The two primary and researched subclasses of univalent functions are S* and C, and as we will demonstrate in the following, Both the subclass are subsets of S and so provide examples of natural subclasses of S. The first reference to starlike and convex functions appears functions was introduced by Robertson in 1936. Kaplan (1952) has generalized convex and starlike functions and established the concept of close-to-convex functions. We can demonstrate that all of the attributes of functions in the "larger" classes are shared by their subclasses by examining the inclusion relations through classes of functions. The following chain is satisfied by the inclusion relations for the classes of starlike, convex, and close-to-convex functions:

$$C \subset\ S^* \subset K \subset S$$

According to Pommerenke (1966) was the person who initially examined Hankel's determinant for the class S of univalent functions given by (1.6). He identified q^{th} Hankel determinant of for $n, q \in \mathbb{N}$ in and proved that $H_q(n) = O(1)n^{k\sqrt{q}-\frac{q}{2}}$ where $k = 16p\sqrt{p}$ when $f\ \in S$. He proved for functions in S that $\left|H_q(n)\right| < O(1)n^{-\left(\frac{1}{2}+\beta\right)q+\frac{3}{2}}$, where $\beta > \frac{1}{4000}$ for $q \geq 2$., its equivalent to $|H_2(2)| < O(1)n^{\frac{1}{2}-2\beta}$. Therefore, Hayman (1966) defined the result where $H_2(n) = O(1)n^{1/2}$ when $f\ \in S$. Noonan and Thomas (1976) proved two result where $q = 1$ and $p > \frac{1}{4}$, then $H_q(n) = O(1)n^{2p-1}$ and if $q \geq 2$ and $p \geq 2(q-1)$, then $H_q(n) = O(1)n^{2pq-q^2}$ still the function is less precisely univalent.

Later in 1976. They, publish a paper to extends and unifies previously known results concerning this problem (Noonan & Thomas, 1976). He determine the growth rate of the second Hankel determinant using mean p-valent function. Noor (1983) determined the rate of growth $H_q(n) as\ n\ \rightarrow\ \infty$ for the functions in S with a bounded boundary. Ehrenborg (2000) studied the Hankel determinant of exponential polynomials. Layman (2001) study on The Hankel transform of an integer sequence is defined and some of its characteristics are explained. It is shown that the Hankel transform of a sequence S is identical the Hankel transform of the Binomial or Invert transform of S. If H is the Hankel matrix of a sequence and H=LU is the LU decomposition of H. Further studied is how the Binomial or Invert transform affects the behaviour of the first super-diagonal of U. This results in the classification system for specific integer sequences.

3. Research Methodology

The Systematic Literature Review (SLR) technique was applied in this study to gather, identify, and evaluate several studies on coefficient inequality using any subclass. SLR is a type of literature review closely related to various scientific techniques to prevent systematic or prejudicial mistakes. The recommended reporting criteria for systematic reviews and meta-analysis, or PRISMA, are applied to this study at various phases. Identification, screening, eligibility, and inclusion are these stages. The methodological process for responding to this research topic is shown in Figure 1 below. In addition, 15 articles were further examined according to the data search results, as shown in the chart above. Table 2 provides a summary of the 15 articles.

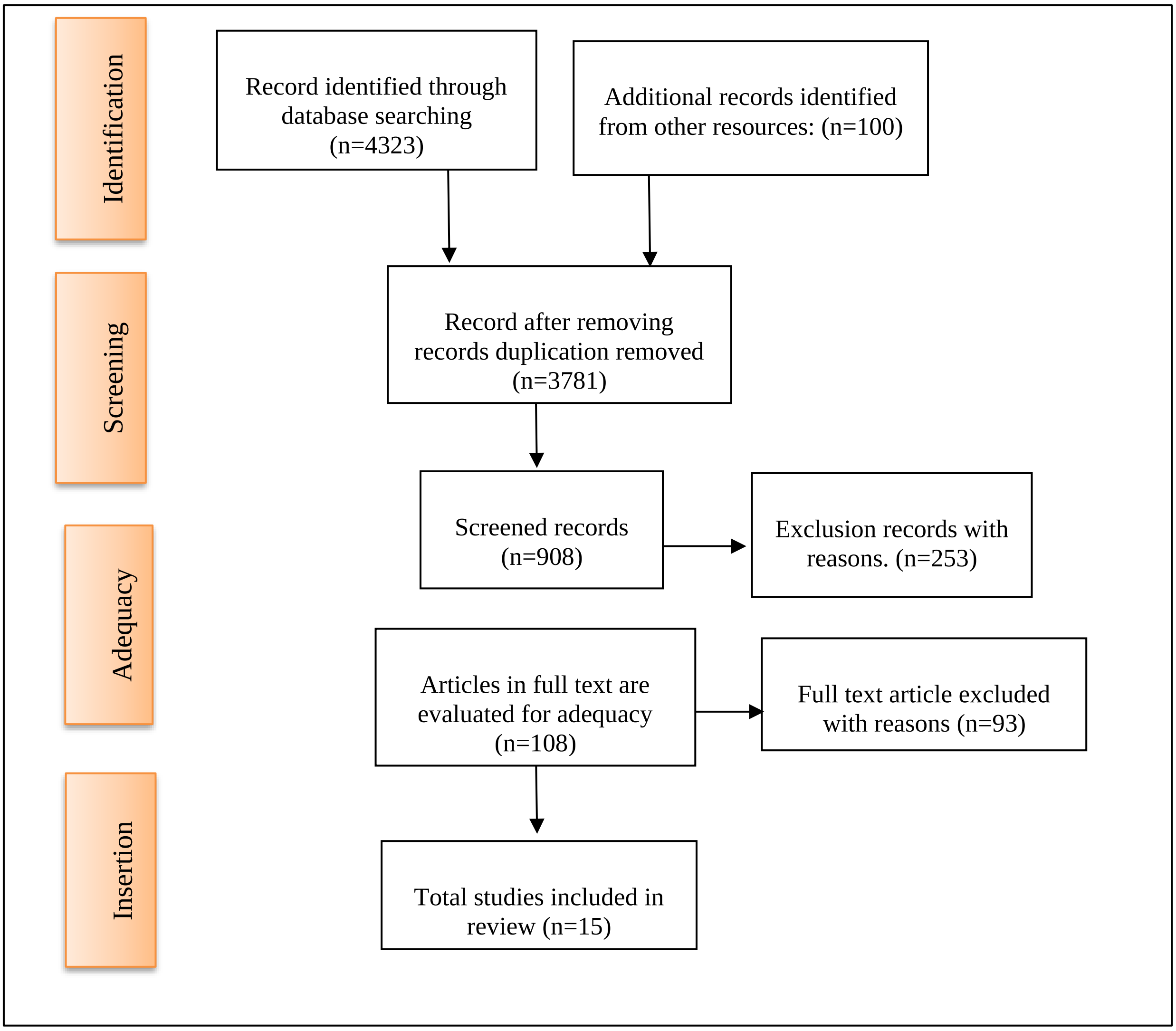

Figure 1. Research Data Search & Selection Flow.

Table 2: Identity of the articles to be analysed further.

No.	Article Title	Year	Author's Name	Journal Name
1.	Second Hankel determinant for close-to-convex functions [1]	2017	Dorina Răducanu and Paweł Zaprawa	C. R. Acad. Sci. Paris, Ser. I
2.	The second Hankel determinant for strongly convex and Ozaki close-to-convex functions [2]	2021	Young Jae Sim, Adam Lecko and Derek K. Thomas	Annali di Matematica Pura ed Applicata (1923 -) (2021)
3.	Fourth Hankel Determinant For The Family of Functions with Bounded Turning [3]	2018	Muhammad Arif, Lubna Rani, Mohsan Raza, and Pawel Zaprawa	Bull. Korean Math. Soc. 55 (2018)
4.	Bounds on third Hankel determinant for close-to-convex functions [4]	2015	J. K. Prajapat, Deepak Bansal, Alok Singh and Ambuj K. Mishra	Acta Univ. Sapientiae, Mathematica, 7, 2 (2015)
5.	Third Hankel determinant for bounded turning functions of order alpha [5]	2015	D. Vamshee Krishnaa, B. Venkateswarlua and T. RamReddy	Journal of the Nigerian Mathematical Society 34 (2015)
6.	Fourth Hankel Determinant for a subclass of analytic functions related to modified sigmoid functions [6]	2021	Hatun Ozlem Guney and Busra K Orfeci	Int. J. Open Problems Compt. Math., Vol. 14
7.	The Second Hankel Determinant for a Certain Class of Bi-Close-to-Convex Functions [7]	2019	Hatun Ozlem Guney , Gangadharan Murugusundaramoorthy and Hari Mohan Srivastava	Results in Mathematics volume 74, Article number: 93 (2019)
8.	Third Hankel determinant for univalent starlike functions [8]	2021	Paweł Zaprawa, Milutin Obradović and Nikola Tuneski	RACSAM (2021)
9.	Hankel Determinant for a Subclass of Bi-Univalent Functions Defined by Using a Symmetric q-Derivative Operator. [9]	2022	H. M. Srivastavaa, Şahsene Altınkayab and Sibel Yalcin	Filomat 32:2 (2018)
10.	Geometric Properties for a New Class of Analytic Functions Defined by a Certain Operator [10]	2022	Daniel Breaz, Gangadharan Murugusundaramoorthy and Lumini ta-Ioana Cotîrlˇa	Symmetry 2022, 14

11.	Certain subclasses of bi-univalent functions associated with the Hohlov operator [11]	2013	H. M. Srivastava1 G. Murugusundaramoorthy and N. Magesh	Global Journal of Mathematical Analysis, 1 (2) (2013)
12.	The sharp bound of the third Hankel determinant for some classes of analytic functions [12]	2018	Bogumi la Kowalczyk, Adam Lecko, Millenia Lecko, and Young Jae Sim.	Bull. Korean Math. Soc. 55 (2018)
13.	An Investigation of the Third Hankel Determinant Problem for Certain Subfamilies of Univalent Functions Involving the Exponential Function [13]	2019	Lei Shi, Hari Mohan Srivastava, Muhammad Arif and Shehzad Hussain and Hassan Khan	Symmetry 2019, 11,
14.	Study Of Some Subclasses Of Univalent Functions and Their Radius Properties [14]	2006	S. Ponnusamy and S. K. Sahoo	Kodai Math. J. 29 (2006)
15.	An Upper Bound to the Second Hankel Determinant for New Class of Univalent Functions [15]	2022	Mallikarjun G. Shrigan	Asian-European Journal of Mathematics Vol. 1, No. 1 (2010)

4. Data Collection and Analysis

This research discovered information from sources via electronic databases such as Google Scholar, Springer Link, Hindawi, Research Gate, and Scorpus. In data search, various keywords are utilized, including the Univalent function, Hankel Determinant, Fkete-szego Function, and upper bound. Furthermore, the researchers analyzed data using a variety of criteria. The researcher developed the analysis criteria in this study by referring to the requirements completed by previous researchers. The SLR model equation, which stands for Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA), was used to choose these criteria. The publications selected are from renowned scientific journals. Table 3 displays the information gathered from the papers considered in this investigation.

Table 3: Data collected from the articles.

No.	Article Title	Purpose of Studies	Type of subclass	Properties
1.	Second Hankel determinant for close-to-convex functions [1]	To obtain the estimation of this expression, called the second Hankel determinant, for c_0, i.e., the subset of C consisting of functions f that satisfies in the unit disk the inequality with a starlike function g.	close-to-convex functions	Hankel determinant and upper bound

2.	The second Hankel determinant for strongly convex and Ozaki close-to-convex functions [2]	To obtain the second Hankel determinant for the subclass of ozaki close-to-convex functions.	close-to-convex functions	Hankel determinant and upper bound
3.	Fourth Hankel Determinant For The Family of Functions with Bounded Turning [3]	To find the fourth Hankel determinant for the class of functions with bounded turning. We also investigate for 2-fold symmetric and 3-fold symmetric functions	Starlike function and convex function	Hankel determinant and upper bound
4.	Bounds on third Hankel determinant for close-to-convex functions [4]	To obtained upper bound on third Hankel determinant for the functions belonging to the class of close-to-convex functions	close-to-convex functions	Hankel determinant, upper bound And Fkete-Szego function
5.	Third Hankel determinant for bounded turning functions of order alpha [5]	To obtain an upper bound to the Third Hankel determinant denoted by $H_3(1)$ for certain subclass of univalent functions, using Toeplitz determinants.	Starlike function	Hankel determinant, upper bound and Toeplitz determinants
6.	Fourth Hankel Determinant for a subclass of analytic functions related to modified sigmoid functions [6]	To study the fourth Hankel determinant for a subclass of starlike functions associated with modified sigmoid function and also determine an upper bound of the fourth Hankel determinant for the functions in this class.	Starlike function	Hankel determinant, coefficient estimates and modified sigmoid function
7.	The Second Hankel Determinant for a Certain Class of Bi-Close-to-Convex Functions [7]	investigate the upper bound associated with the second Hankel determinant $H_2(2)$ for a certain class of bi-close-to-convex functions which we have introduced	close-to-convex	Hankel determinant, upper bound And Fkete-Szego function
8.	Third Hankel determinant for univalent starlike functions [8]	To apply the correspondence between starlike functions and Schwarz functions	Starlike function	Hankel determinant, Schwarz functions and upper bound

9.	Hankel Determinant for a Subclass of Bi-Univalent Functions Defined by Using a Symmetric q-Derivative Operator. [9]	Introduced various properties of a newly-constructed subclass of the class of normalized bi-univalent functions in the open unit disk, which is defined here by using a symmetric basic derivative operator.	New sub class	q-derivative and Hankel determinant
10.	Geometric Properties for a New Class of Analytic Functions Defined by a Certain Operator [10]	To define and explore a certain class of analytic functions involving the (p,q)-Wanas operator related to the Janowski functions..	New sub class	Integral operator, Fekete–Szegö and partial sums
11.	Certain subclasses of bi-univalent functions associated with the Hohlov operator [11]	To introduce and investigate two new subclasses of the function class Σ of bi-univalent functions defined in the open unit disk, which are associated with the Hohlov operator, that is, a familiar special case of the widely- (and extensively-) investigated Dziok-Srivastava linear operator.	New Subclass	Hohlov operator, linear operator and coefficient estimates.
12.	The sharp bound of the third hankel determinant for some classes of analytic functions [12]	To proved the sharp inequality $\lvert H_{(3,1)}(f)\rvert \leq 4$ and $\lvert H_{(3,1)}(f)\rvert \leq 1$ for analytic functions f.	Starlike function and convex function	Hankel determinant and upper bound
13.	An Investigation of the Third Hankel Determinant Problem for Certain Subfamilies of Univalent Functions Involving the Exponential Function [13]	To find the bounds of Hankel determinant of order three. and estimate of third Hankel determinant for the family in this work improve the bounds which was investigated recently. Moreover, the same bounds have been investigated for 2-fold symmetric and 3-fold symmetric functions.	Starlike function and convex function.	Hankel determinant, coefficient estimates and upper bound

14.	Study Of Some Subclasses of Univalent Functions and Their Radius Properties [14]	To determine necessary and sufficient coefficient conditions for certain class of functions to be in f(α). Also radius properties are consider for f(α). -class of function to be in Also, radius properties are considered for f(α)-class in the class f.	Starlike function	Radius properties
15.	An Upper Bound to the Second Hankel Determinant for New Class of Univalent Functions [15]	Introduce and investigate a newly-constructed class of univalent functions in the open disk. For this function class, we obtain upper bounds for the second Hankel determinant $H_2(2)$.	Convex Function	Hankel determinant and upper upper bound

5. Results and Discussion

5.1 Purpose of the studies

Based on table 3 aimed to find the coefficient inequality using different types of subclass using the existing or modified function has been introduced by Robertson (1936) and Kaplan (1952). The data analysis utilized in this study is the content analysis concerning this SLR. This technique determines descriptive trends in studies undertaken on a specific topic. This technique analyses data in three steps: (1) the purpose of the studies, (2) the type of subclass used, and (3) properties. Table 3 shows the selected articles have the same goal: establishing the upper bound for Hankel Determinants using any subclass in a univalent function. Some articles focus on generalizing an existing subclass or defining a new subclass. The Hankel determinant is used in most articles to solve the coefficient inequality. Therefore, it might be obtained that most past researchers improved the upper bound that previous researchers previously examined by using the new properties. Certain articles also defined a new subclass and introduced various properties for them to introduce. This result motivates more research to construct an analysis on this topic.Besides that, the future researcher needs to analyze the relationships between subclass and find the suitable properties to get improvised than the previous researcher. The researcher may gain more knowledge regarding the properties of the Univalent function and improve the decision to choose the appropriate type of subclass and method.

5.2 Type of subclass

Table 4. Targeted Populations in The Studies

Article Number	Starlike Function (S^*)	Convex Function (C)	Close-to-Convex Function (K)	New Subclass
Article [1]			✓	
Article [2]			✓	
Article [3]	✓	✓		
Article [4]			✓	
Article [5]	✓			
Article [6]	✓			
Article [7]			✓	
Article [8]	✓			
Article [9]				✓
Article [10]				✓
Article [11]				✓
Article [12]	✓	✓		
Article [13]	✓	✓		
Article [14]	✓			
Article [15]		✓		
Total Article	**n=7**	**n=4**	**n=4**	**n=3**

Table 4 above illustrates several types of subclasses used in the studies. The type of subclass is based on the study's objective. Seven of the fifteen articles used the Starlike function; most researchers used this subclass. Since Starlike function is a functions with well-defined and straightforward mathematical properties among the three existing subclass. Four articles used the Convex function and Close-to-convex function. Furthermore, three articles make use of a new subclass. Introducing new subclasses allows researchers to focus on particular types of functions and investigate their unique characteristics. They also desire to study specific properties of these functions or to explore connections with other areas of mathematics. We can determine from this data that there are accessible coefficient inequalities for the univalence function. As a result, more papers should be written in the future about using subclass for close-to-convex functions or New subclass.

5.3 Properties

Table 5: Properties Used in The Studies

Article Number	Hankel Determinant	Upper Bound	Fkete-Szego Function	Coefficient Estimates	Schwarz Function	Radius Properties
Article [1]	✓	✓				
Article [2]	✓	✓				
Article [3]	✓	✓				
Article [4]	✓	✓	✓			
Article [5]	✓					
Article [6]	✓					
Article [7]	✓	✓	✓			
Article [8]	✓	✓			✓	
Article [9]						
Article [10]	✓					
Article [11]				✓		
Article [12]	✓	✓				
Article [13]	✓	✓		✓		
Article [14]						✓
Article [15]	✓	✓				
Total Article	n=14	n=10	n=2	n=2	n=1	n=1

Article Number	Partial Sum	Hohlov & Linear Operator	Toeplitz Determinant	Modified Sigmoid	Integral Operator	Q-Derivatives
Article [1]						
Article [2]						
Article [3]						
Article [4]						
Article [5]			✓			
Article [6]				✓		
Article [7]						
Article [8]						
Article [9]						
Article [10]	✓				✓	✓
Article [11]		✓				

Article [12]						
Article [13]						
Article [14]						
Article [15]						
Total Article	n=1	n=1	n=1	n=1	n=1	n=1

Table 5 illustrates the properties used to find the coefficient inequality. There are 12 properties that have been introduced by the previous researcher. 13 article uses Hankel Determinant properties which is the majority of properties used by authors. Ten articles apply the upper bound. Two articles used the Fkete-Szego function and coefficient estimates, while only one article used the other remaining properties Schwarz Function, Radius Properties, Partial Sum, Hohlov & Linear Operator, Toeplitz Determinant, Toeplitz Determinant, Integral Operator and Q-Derivatives. Most researchers use Hankel determinants because Hankel determinants play a crucial role in establishing coefficient inequalities for certain classes of univalent functions. In particular, they are used to derive bounds on the magnitude of the coefficients in the power series expansion of univalent functions. More research is needed to introduce various new properties for the newly introduced subclass to perform better results than previous research.

6. Conclusion and Recommendation

This study is an SLR on the development of coefficient inequality using any subclass, which has analyzed 15 articles from the year 20206 until 2022 last year in reputable international journals and selected based on predetermined criteria. This article clearly illustrates the SLR of coefficient inequality using any subclass and current trends by identifying, classifying, and synthesizing research results based on research themes. Three main themes are found based on data analysis: the purpose of the study, type of subclass and properties. A drawback of this study is that it only looked at a few articles, which might not accurately reflect the scope of the research currently conducted in this field.

Finally, our analysis concludes that most researchers use the Starlike function subclass to solve the coefficient inequality. However, we suggest that future researchers use the Close-to-Convex function or define a new subclass since it will enhance more knowledge for another researcher to construct this subclass and apply various new properties. Hence, the result obtained from the researcher improves the bounds investigated recently by previous authors. Involving more variation, researchers can get valuable information and increase the validity of their literature review articles.

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9. Conflict of Interest

The authors have no conflicts of interest to declare.

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