Neutrosophic cross entropy-based discrimination of antioxidant potential and polyphenolic contents of *Arisaema tortuosum*

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Abstract: The study presents the utilization of an innovative neutrosophic cross entropy-based technique for the discrimination of the antioxidant potential of *Arisaema tortuosum* leaf extract based on polyphenolic content. The effect of three extraction techniques, namely, Soxhlet extraction, ultrasound-assisted extraction, and maceration, have been analyzed on the percentage yield of the extract. The effect of solvents, namely, methanol, chloroform and hexane, on the percentage yield has also been explored. The leaf extract was found to exhibit significant antioxidant potential and polyphenolic content. Substantial discrimination was observed among antioxidant potential and polyphenolic contents with minimum neutrosophic cross entropy values designated to the extant higher amount of polyphenols in *A. tortuosum* leaf extract. The proposed neutrosophic cross entropy-based technique is beneficial for further mathematical treatments because of its symmetric nature in comparison with the existing methods, which may indicate vagueness in the evaluation information under certain situations and thus affects the prognosis analysis.

Keywords: Cross entropy, Fuzzy Sets, Neutrosophic Sets, *Arisaema tortuosum*, TPC, antioxidant potential.

1. Introduction

The neutrosophic sets (NSs) proposed by Smarandache have played an intelligent role in dealing with real-world problems containing imprecise, inconsistent and indeterminate information [1]. One of the characteristics of NSs is that they include a non-standard unit interval that includes membership gradations such as "true," "indeterminate," and "false" [2]. Since the indeterminacy inherited in the NSs depend upon the "true" and "false" values, the neutrosophic cross entropy measures (NCEMs) can handle real-world problems with imprecise, inconsistent

and incomplete information [1]. Ishtiaq et al. (2021) initiated the ideas of orthogonal NMSs, investigated many fixed points results, and validated their findings by providing some non-trivial counterexamples [3]. Uddin et al. (2021) established the concepts of orthogonal controlled fuzzy metric-like spaces to establish some fixed point theorems and validated the main findings [4]. Also, the authors provided some counterexamples and an application to the fuzzy Fredholm IE of the second kind. Javed et al. (2021) idealized the ideas of fuzzy b-metric like spaces to prove some interesting fixed point theorems and validated their findings by applying the fuzzy Fredholm IE of the first kind [5]. Ishtiaq, Hussain, and Al Sulami (2022) introduced the concept of fuzzy rectangular metric-like spaces and proved some exciting results, combined with single and multi-valued mappings, of fixed point theory [6].

Ali et al. (2022) provided several unique solutions to non-linear fractional differential equations for weekly compatible and contractive functions under the environment of neutrosophic metric spaces (NMSs) [7]. Hussain, Al Sulami, and Ishtiaq (2022) introduced the concept of intuitionistic fuzzy rectangle metric and b-metric spaces as well as neutrosophic rectangular metric and b-metric spaces to prove some important fixed point results along with an application to the Fredholm Integral equation (IE) of the second kind [8]. Hussain et al. (2022) also confirmed some Banach fixed point results by generalizing the concept of pentagonal controlled fuzzy and fuzzy extended hexagonal metric spaces [9]. The authors provided some counterexamples in support of their findings and also gave an application to dynamic marketing. Farheen et al. (2022) gave authentic proof of the Banach fixed point theorem under intuitionistic fuzzy double-controlled metric spaces. To support their findings, the authors provided an application to the fuzzy Fredholm IE of the second kind [10]. Saleem et al. (2022) idealized the ideas of graphical fuzzy metric-like spaces and proved the Banach fixed point theorem. To validate their outcomes, the authors solved a non-linear fractional differential equation in the context of graphical fuzzy metric spaces [11]. Unfortunately, the existing literature on NCEMs mainly covers asymmetrical aspects ignoring the symmetrical and undefined parameters [12]. To overcome these shortcomings and limitations and to handle complex real-life problems with ambiguity and vagueness, it is necessary to develop an efficient methodology that can accurately discriminate the desired parameters.

Since ancient times, medicinal plants have been explored to heal various diseases because of the availability of vital volatile organic compounds or phytochemicals exhibiting medicinal properties [13]. The biomedical potential of any plant is explored based on phytochemical analysis of the extracts of its various parts, especially in terms of antioxidant potential [14]. Discrimination of antioxidant potentials and polyphenolic contents of bioactive plant extract with medicinal and therapeutic potential needs to be explored in scientific interest [15]. Castellano et al.

(2013) have determined the number of classes and classification levels for the flavonoids using information entropy [16]. However, there is no study available in the literature on the discrimination of the medicinal potential with the phytochemical constituents of medicinal plants based on fuzzy sets (FSs) theory. This observation reinforces the necessity to develop a superior and intelligent methodology that can optimize the phytochemical extraction of medicinal plants.

Arisaema tortuosum is a medicinal herb with multiple therapeutic uses because of the availability of volatile organic compounds, including flavonoids, terpenoids, polyphenols etc. [17]. So far, no neutrosophic cross entropy base methodology has been established and applied for studying the phytochemical analysis of *A. tortuosum*. The conventional Information Theory approaches based upon the theory of fuzzy sets (FSs) and neutrosophic sets (NSs) can be used in discriminating antioxidant potentials and polyphenolic contents of the extract obtained from aerial parts of bioactive plants. In the current study, a classy trigonometric neutrosophic cross entropy measure (NCEM) hinging on the two single-valued neutrosophic sets (SVNSs) is proposed and applied to discriminate the polyphenolic contents and antioxidant potential in the extracts obtained from the aerial parts of *A. tortuosum*. The subsequent development of the proposed work has been arranged in Figure 1 and described ahead.

Section 2 discusses the materials and methodology deployed for obtaining the extract and assessing the antioxidant potential and polyphenolic contents. The antioxidant potential has been analyzed in the following terms:

1. 1,1-diphenyl-2-picryl-hydrazyl (DPPH) assay
2. 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) radical scavenging assay
3. Ferric reducing antioxidant power (FRAP) assay

The polyphenolic content has been obtained in the following terms:

1. Total polyphenolic content (TPC)
2. Total flavonoid content (TFC)

The section also provides information about establishing the proposed cross-entropy measures. Section 3 provides results for the experimental and numerical analysis to provide the discrimination among antioxidant potential and polyphenolic contents, with the findings summarized in section 4.

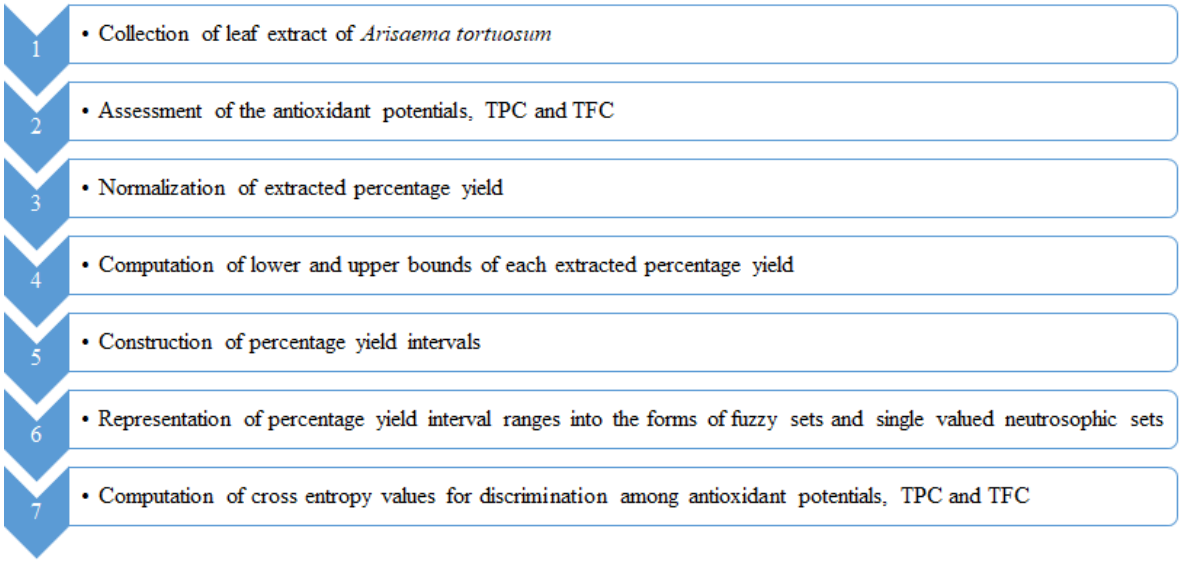


Figure 1. A detailed schematic flow chart of the underlying methodology

2. Materials and Methods

2.1. Materials

The plant was collected from the Himalayan region of Dharamshala (Naddi), Himachal Pradesh. Young leaves of *Arisaema tortuosum* were selected and washed with regular and double distilled water to expel the residue and dust particles over their surface. After draining free water, the obtained material was dried in a shady region at room temperature for 30 days and ground to get the powdered form. The various chemicals utilized in the present work were procured from Merck Ltd. Mumbai and used as such. Double distilled water was used to prepare all the formulations.

2.2. Leaf extract preparation

Three solvents of different polarities, chloroform, methanol and hexane, were used to extract the sample in the powdered form. The plant material was extracted in triplicate for 30 minutes with 100 mL of solvent using Soxhlet extraction (SE) [18], Ultrasound aided extraction (UAEM) [19], and Maceration extraction (ME) [20]. Through a rotary vacuum evaporator at 45 ^{o}C, the obtained extract was evaporated to dryness and then preserved for further investigations at a low temperature.

2.3. Determination of polyphenolic content

The Folin-Ciocalteu technique was deployed to measure the TPC. 20 µL of leaf extract (5 mg/mL) in DMSO (25% v/v) was amalgamated to diluted Folin–Ciocalteu reagent (100 µL) with agitation for 1 minute. 75 µL of Na_2CO_3 solution (100 mg/mL) was added and again agitated for 1 minute. The mixture was left for 2 hours, and the absorbance of the coloured solution was monitored at 750 nm through a UV-Vis spectrophotometer (Agilent Cary-60) with gallic acid as a calibration standard. TPC was estimated as the mg equivalents of gallic acid / g of leaf extract (mg GAE/g).

The aluminum chloride technique was deployed to access the TFC of the extracts. 20 μL of leaf extract (5 mg/mL) in DMSO (25% v/v) was added to 10 μL of $AlCl_3$ (10%) and 10 μL of CH_3COOK (1 M). The mixture was diluted with double distilled water to achieve a final volume of 200 μL and left for 30 minutes. The absorbance of the solution was monitored at 415 nm using quercetin as the reference. TFC was estimated as mg quercetin equivalents/ g of leaf extract (mg QE / g).

2.4. Determination of antioxidant potential

Standard methods were used to investigate the antioxidant potential of the extracts quantitatively. 3 ml of the freshly available DPPH solution (0.1 mM) was well mixed with 0.2 ml of extract (10-100 μg/mL) and incubated for thirty minutes in the dark. The absorbance was monitored at 517 nm. The scavenging impact of the extracts against DPPH free radicals was determined by employing Ascorbic acid as a standard.

3 mL of FRAP solution was mixed with leaf extract (10-100 μg/mL) and then incubated for 30 min. The absorbance of the obtained solution was measured at 593 nm. The ferrous sulphate was utilized as standard, and FRAP was expressed as ferrous II equivalents in mg per g of the leaf extract (mg Fe (II) /g).

180 μL of ABTS solution was added to 20 μL of leaf extract (10-100 μg/mL) and incubated for 30 min. The absorbance of the obtained solution was monitored at 734 nm using ascorbic acid as standard. The ABTS scavenging potential was determined in terms of ABTS radical scavenging %.

2.5. Neutrosophic cross entropy measure

2.5.1. A symmetric fuzzy cross entropy measure

The cross-entropy information measures in the reported literature face a major drawback because of their asymmetrical nature. They return undefined or meaningless when their membership functions conceive zero value in some mathematical treatments. The following **Theorem 1** overcomes the shortcomings mentioned above and its limitations.

Theorem 1 Set $l_1 = {}_A\mu(x_i)\left(1-{}_A\mu(x_i)\right)$. Let $A=\left(\prec x_i, {}_A\mu(x_i)\succ \forall x_i \in X\right)$ be any FS belonging to $\mathrm{X}=\left(x_1, x_2, x_3, .., x_n\right)$. Then

$$H_{\mathrm{FS}}^{\mu}(\mathrm{A}) = \sum_{i=1}^{n}\left[\tan\left(\frac{3}{2}\right) - \tan\left(\frac{3}{2+2\sqrt{l_1}}\right)\right] \tag{1}$$

is a reliable measure (**Def. 1)** where $H_{\mathrm{FS}}^{\mu}(\mathrm{A})$ indicates the mathematical fuzziness value of the FS A. Moreover, its minimum value is zero and $\mathrm{Max}.H_{\mathrm{FS}}^{\mu}(\mathrm{A}) = \left(\tan\left(\frac{3}{2}\right) - \tan(1)\right)n,$ where the cardinality of the FS A is represented by n.

Proof (i) Clearly $H_{FS}^{\mu}(A) \geq 0 \forall A \in X$ with equality if ${}_A\mu(x_i) = 0$ or 1.

(ii) $H_{FS}^{\mu}(A)$ doesn't change even if ${}_A\mu(x_i)$ is replaced with $1-{}_A\mu(x_i)$.

(iii) Concavity of $H_{FS}^{\mu}(A)$ for each ${}_A\mu(x_i)$:

$$\frac{\partial H_{FS}^{\mu}(A)}{\partial {}_A\mu(x_i)} = \frac{3\left(1-2\,{}_A\mu(x_i)\right)\sec^2\left(\frac{3}{2+2\sqrt{l_1}}\right)}{4\sqrt{l_1}\left(1+\sqrt{l_1}\right)^2} \tag{2}$$

$$\frac{\partial^2 H_{FS}^{\mu}(A)}{\partial {}_A\mu^2(x_i)} = -\frac{3\sec^2\left(\frac{3}{2+2\sqrt{l_1}}\right)\left(\begin{array}{l}16\,{}_A\mu^3(x_i)+4\sqrt{l_1}+1\\ +3{}_A\mu(x_i)+8\,{}_A\mu^2(x_i)\sqrt{l_1}\\ +3\left(1-2{}_A\mu(x_i)\right)^2\sqrt{l_1}\tan\left(\frac{3}{2+2\sqrt{l_1}}\right)\end{array}\right)}{8l_1^{\frac{3}{2}}\left(1+\sqrt{l_1}\right)^4} \leq 0 \quad \text{for each}$$

${}_A\mu(x_i) \in [0,1]$. This justifies the concavity.

(iv) There exists a maximum value of $H_{FS}^{\mu}(A)$ with respect to each ${}_A\mu(x_i)$ owing to its concavity property. Using (2), this maximum value arises when $\frac{\partial H_{FS}^{\mu}(A)}{\partial {}_A\mu(x_i)} = 0$ which yields ${}_A\mu(x_i) = \frac{1}{2}$. From (1)

$$\text{Max.}H_{FS}^{\mu}(A) = H_{FS}^{\mu}(A)\Big|_{{}_A\mu(x_i)=\frac{1}{2}} = \left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n. \tag{3}$$

The concavity of $H_{FS}^{\mu}(A)$ is evident in Figure 2.

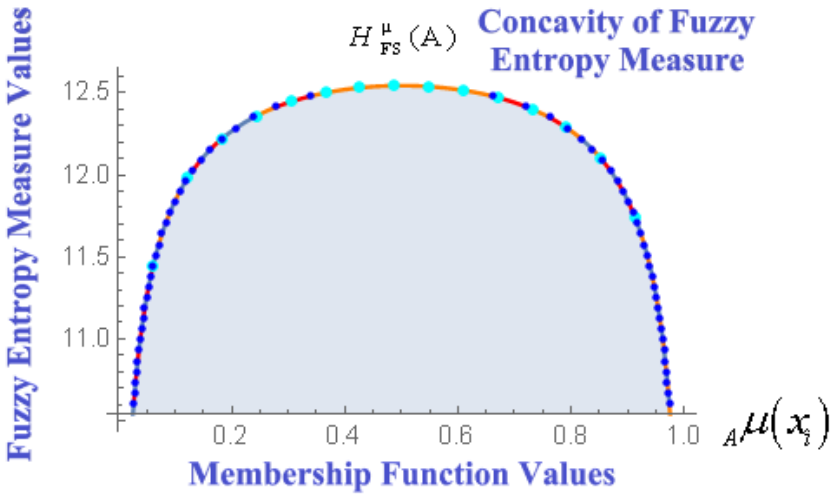


Figure 2. Concavity of fuzzy entropy measure $H_{FS}^{\mu}(A)$ with respect to ${}_A\mu(x_i)$

Theorem 2 Set $l_2 = {}_A\mu(x_i) + {}_B\mu(x_i), l_3 = {}_A\mu^2(x_i) + {}_B\mu^2(x_i), l_4 = {}_A\mu(x_i)\,{}_B\mu(x_i)$, then $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})$ represents a valid TSFCE measure that hinges on two FSs A and B where

$$\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B}) = \sum_{i=1}^{n}\left[-6\tan(1) + (2+l_2)\tan\left(\frac{2+l_2}{2+2\sqrt{l_3}}\right) + (4-l_2)\tan\left(\frac{4-l_2}{2+2\sqrt{l_4}}\right)\right] \tag{4}$$

Proof. It is easy to verify the symmetric nature of $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})$ as $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B}) = \mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{B},\mathrm{A}) \forall A, B \in S(X)$. Further, $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})$ remains unchanged on replacing ${}_A\mu(x_i), {}_B\mu(x_i)$ with $1-{}_A\mu(x_i), 1-{}_B\mu(x_i)$ into equation **(3)**. To establish $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B}) \geq 0,$ we shall first establish the following **Lemma 1 .**

Lemma 1 Define $l_5 = {}_A\mu^2(x_i) + {}_B\mu^2(x_i)$. There exists the inequality $\sqrt{\frac{l_5}{2}} \geq \sqrt{l_3}$ with equality whenever ${}_A\mu(x_i) = {}_B\mu(x_i) \in [0,1]$.

Proof. In our notations,

$$\frac{l_5}{2} - \frac{l_2^2}{4} = \left(\frac{{}_A\mu(x_i) - {}_B\mu(x_i)}{2}\right)^2 \geq 0 \;\Rightarrow \sqrt{\frac{l_5}{2}} \geq \frac{l_2}{2} \forall {}_A\mu(x_i), {}_B\mu(x_i) \in [0,1] \tag{5}$$

with equality if ${}_A\mu(x_i) = {}_B\mu(x_i) \forall i = 1,2,...,n.$

Define $m_0 == \left(\frac{\sqrt{{}_A\mu(x_i)} + \sqrt{{}_B\mu(x_i)}}{2}\right)^2$ and consider

$$\frac{l_2}{2} - m_0 = \left(\frac{\sqrt{{}_A\mu(x_i)} - \sqrt{{}_B\mu(x_i)}}{2}\right)^2 \geq 0 \Rightarrow \frac{l_2}{2} \geq m_0 \forall {}_A\mu(x_i), {}_B\mu(x_i) \in [0,1] \tag{6}$$

with equality if ${}_A\mu(x_i) = {}_B\mu(x_i) \forall i = 1,2,...,n.$

Again $m_0 - \sqrt{l_3} = \left(\frac{\sqrt{{}_A\mu(x_i)} - \sqrt{{}_B\mu(x_i)}}{2}\right)^2 \geq 0$

$$\Rightarrow m_0 \geq \sqrt{l_3} \forall {}_A\mu(x_i), {}_B\mu(x_i) \in [0,1] \tag{7}$$

with equality if ${}_A\mu(x_i) = {}_B\mu(x_i) \forall i = 1,2,...,n.$

We can combine the resulting inequalities **(5-7)** to get the desired result.

The outcomings of **Lemma 1** can be re-designed as

$$\frac{l_5}{2} \geq l_3 \Rightarrow \frac{{}_A\mu^2(x_i) + {}_B\mu^2(x_i)}{2} \geq {}_A\mu(x_i)\,{}_B\mu(x_i)$$

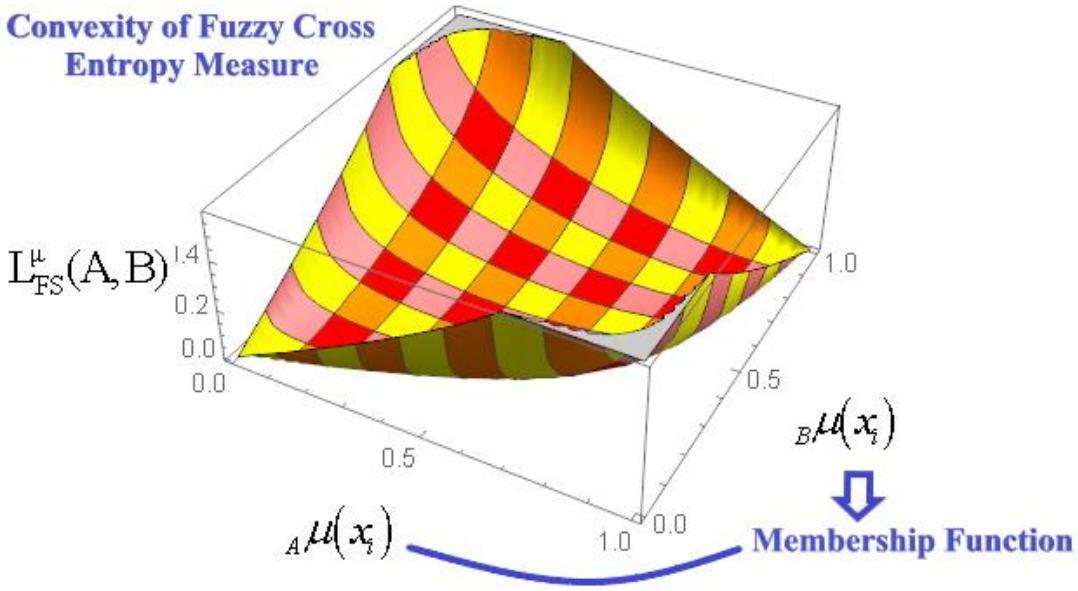
$$\Rightarrow \frac{\left({}_A\mu(x_i) + {}_B\mu(x_i)\right)^2 - 2\,{}_A\mu(x_i)\,{}_B\mu(x_i)}{2} \geq {}_A\mu(x_i)\,{}_B\mu(x_i)$$

$$\frac{l_2^2}{2} - l_3 \geq l_3 \Rightarrow \frac{l_2^2}{4} \geq l_3 \Rightarrow \frac{l_2}{2} \geq \sqrt{l_3} \Rightarrow \frac{l_2}{2} + 1 \geq \sqrt{l_3} + 1$$

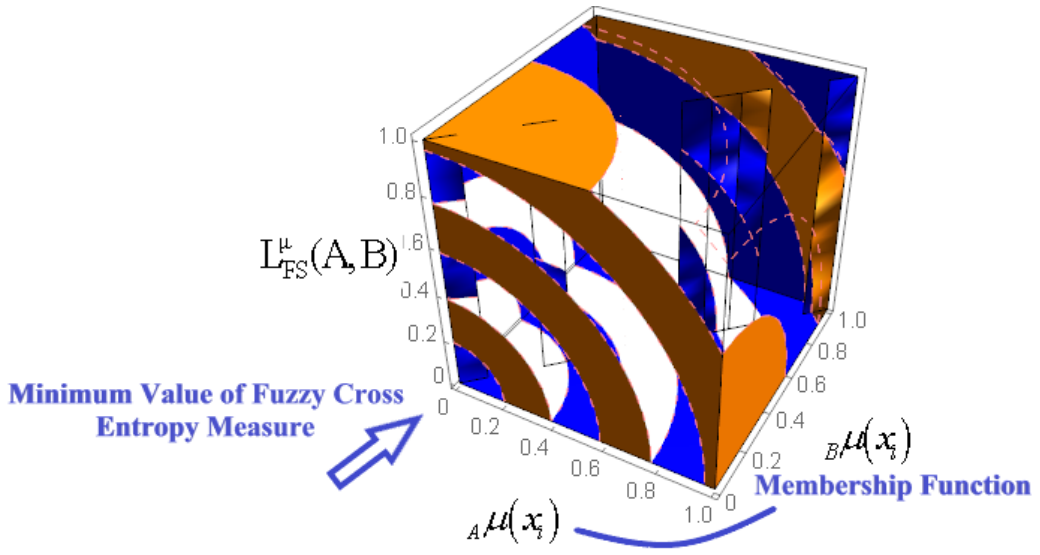
$$\Rightarrow \frac{2+l_2}{2+2\sqrt{l_3}} \geq 1 \tag{8}$$

After taking tangent of the undergoing inequality **(8)** yields

$$(2+l_2)\tan\left(\frac{2+l_2}{2+2\sqrt{l_3}}\right) \geq (2+l_2)\tan 1 \tag{9}$$



(a)



(b)

Figure 3. (a) Convexity and (b) maximum/minimum values $L^{\mu}_{FS}(A,B)$

On the similar pattern, the replacement of $_A\mu(x_i); _B\mu(x_i)$ with $1-_A\mu(x_i); 1-_B\mu(x_i)$ yields

$$\left(4-l_2\right)\tan\left(\frac{4-l_2}{2+2\sqrt{l_4}}\right)\geq\left(4-l_2\right)\tan 1 \tag{10}$$

We can simply add **(9)** and **(10)** and then take summation over $i=1$ to n for getting the desired result. That is, $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})\geq 0$ for each ${}_A\mu(x_i),{}_B\mu(x_i)\in[0,1]$ with equality whenever ${}_A\mu(x_i)={}_B\mu(x_i)\forall i=1,2,...,n.$

It will be informative to know that $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})$ discloses its minimum and maximum values as proved in Theorem 3.

Theorem 3. $\exists$ the inequality: $0\leq\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{A}^c)\leq 6\left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n$ where $n\in N$.

Proof. In our notations, if we replace B with its counterpart A^c into the resulting equation **(4)**, then $2+l_2$ changes to 3, $l_3\to l_1, 4-l_2\to 3, l_4\to l_1$.

With these restrictions, the resulting equation **(4)** be rescheduled as

$$\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{A}^c)=\sum_{i=1}^{n}\left[-6\tan(1)+6\tan\left(\frac{3}{2+2\sqrt{l_1}}\right)\right]$$

$$=\sum_{i=1}^{n}\left[6\tan\left(\frac{3}{2}\right)-6\tan(1)-6\left[\tan\left(\frac{3}{2}\right)-\tan\left(\frac{3}{2+2\sqrt{l_1}}\right)\right]\right]=6\,Max.H_{\mathrm{FS}}^{\mu}(\mathrm{A})-6H_{\mathrm{FS}}^{\mu}(\mathrm{A})$$

$$\Rightarrow H_{\mathrm{FS}}^{\mu}(\mathrm{A})=Max.H_{\mathrm{FS}}^{\mu}(\mathrm{A})-\frac{1}{6}\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{A}^c) \tag{11}$$

With the aid of non-negative condition $H_{\mathrm{FS}}^{\mu}(\mathrm{A})\geq 0$, the expression **(11)** yields

$$0\leq\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{A}^c)\leq 6\left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n \tag{12}$$

The inequality expression **(12)** suggests $\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{A}^c)$ as finite since n is finite. Also, readers can easily establish that $0\leq\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})\leq 6\left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n$ which suggests that $\mathrm{Max}.\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})=6\left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n$. Also, the plots displayed in **Figure 3 (a-b)** affirm that $\mathrm{Min}.\mathrm{L}_{\mathrm{FS}}^{\mu}(\mathrm{A},\mathrm{B})$ is zero.

To predict the various antioxidant potentials and polyphenolic contents extracted from the aerial parts of *A. tortuosum,* it becomes essential for us to cultivate the following Theorem 4.

2.5.2. A neutrosophic cross entropy measure

Theorem 2 can be extended to establish another important cross entropy measure based on two SVNSs as follows.

Def. 2 Set $r_2={}_Ai(x_i)+{}_Bi(x_i), r_3={}_Ai(x_i)\,{}_Bi(x_i), r_4=\left(1-{}_Ai(x_i)\right)\left(1-{}_B\,i(x_i)\right)$. Let $A=\left(\prec x,{}_A\mu(x_i),{}_Ai(x_i),{}_Af(x_i)\succ\forall x_i\in X\right); B=\left(\prec x,{}_B\mu(x_i),{}_Bi(x_i),{}_Bf(x_i)\succ\forall x_i\in X\right)$

be any two SVNSs. The amount of fuzziness inherited by the truth membership degree of A and B is given by $L_{FS}^{\mu}(A,B)$ and represented by **(3).** Similarly, as per **Theorem 2,** the amount of fuzziness inherited by the degree of indeterminancy membership of A and B is

$$L_{FS}^{i}(A,B)=\sum_{i=1}^{n}\left[-6\tan(1)+(2+r_2)\tan\left(\frac{2+r_2}{\sqrt{2}+2\sqrt{r_3}}\right)+(4-r_2)\tan\left(\frac{4-r_2}{\sqrt{2}+2\sqrt{r_4}}\right)\right] \quad (13)$$

If we set

$s_2={}_Af(x_i)+{}_Bf(x_i), s_3={}_Af(x_i)\,{}_Bf(x_i), s_4=(1-{}_Af(x_i))(1-{}_Bf(x_i)),$ then the amount of fuzziness inherited by the falsity membership degree of A and B is

$$L_{FS}^{f}(A,B)=\sum_{i=1}^{n}\left[-6\tan(1)+(2+s_2)\tan\left(\frac{2+s_2}{\sqrt{2}+2\sqrt{s_3}}\right)+(4-s_2)\tan\left(\frac{4-s_2}{\sqrt{2}+2\sqrt{s_4}}\right)\right] \quad (14)$$

Hence, $L_{SV}(A,B)$, the proclaimed trigonometric symmetric SVNCE measure, via two SVNSs, A and B, can be obtained as per following expression:

$$L_{SV}(A,B)=L_{FS}^{\mu}(A,B)+L_{FS}^{i}(A,B)+L_{FS}^{f}(A,B) \quad (15)$$

Theorem 4. $\exists$ the inequality: $0\le L_{SV}(A,A^c)\le 18\left(\tan\left(\frac{3}{2}\right)-\tan(1)\right)n$ where, the cardinality of the SVNSs, A and B is represented by $n\in N$

Proof. Set

$\eta_1={}_Ai(x_i)(1-{}_Ai(x_i)), \eta_2={}_A\mu(x_i)+{}_Af(x_i),$

$\eta_3={}_A\mu(x_i)\,{}_Af(x_i), \eta_4=(1-{}_A\mu(x_i))(1-{}_Af(x_i)).$

In our notations, if we replace the SVNS B with its counterpart A^c into the resulting equation **(15)**, then

$$L_{SV}(A,A^c)=\sum_{i=1}^{n}\left[-18\tan(1)+6\tan\left(\frac{3}{2+2\sqrt{\eta_1}}\right)+2(2+\eta_2)\tan\left(\frac{2+\eta_2}{2+2\sqrt{\eta_3}}\right)+2(4-\eta_2)\tan\left(\frac{4-\eta_2}{2+2\sqrt{\eta_4}}\right)\right]$$

$$=\sum_{i=1}^{n}\left[18\tan\left(\frac{3}{2}\right)-18\tan(1)-6\left[\begin{array}{l}3\tan\left(\frac{3}{2}\right)-\tan\left(\frac{3}{2+2\sqrt{\eta_1}}\right)-\left(\frac{2+\eta_2}{3}\right)\tan\left(\frac{2+\eta_2}{2+2\sqrt{\eta_3}}\right)\\ -\left(\frac{4-\eta_2}{3}\right)\tan\left(\frac{4-\eta_2}{2+2\sqrt{\eta_4}}\right)\end{array}\right]\right]$$

$$=6\,Max.L_{SV}(A)-6L_{SV}(A);$$

$$L_{SV}(A)=\sum_{i=1}^{n}\left[3\tan\left(\frac{3}{2}\right)-\tan\left(\frac{3}{2+2\sqrt{\eta_1}}\right)-\left(\frac{2+\eta_2}{3}\right)\tan\left(\frac{2+\eta_2}{2+2\sqrt{\eta_3}}\right)-\left(\frac{4-\eta_2}{3}\right)\tan\left(\frac{4-\eta_2}{2+2\sqrt{\eta_4}}\right)\right] \quad (16)$$

The resulting expression **(16)** represents the desired SVNCE measure with following all the essential conditions:

1. $L_{SV}(A)$ exhibits the concavity property for each $L_{SV}(A)$
2. $L_{SV}(A)=0$ if either ${}_A\mu(x_i)=0, {}_Ai(x_i)=0, {}_Af(x_i)=1.$ or ${}_A\mu(x_i)=1, {}_Ai(x_i)=0, {}_Af(x_i)=0$
3. $L_{SV}(A)\geq 0 \forall A\in W(X)$
4. $L_{SV}(A^c)=L_{SV}(A)$

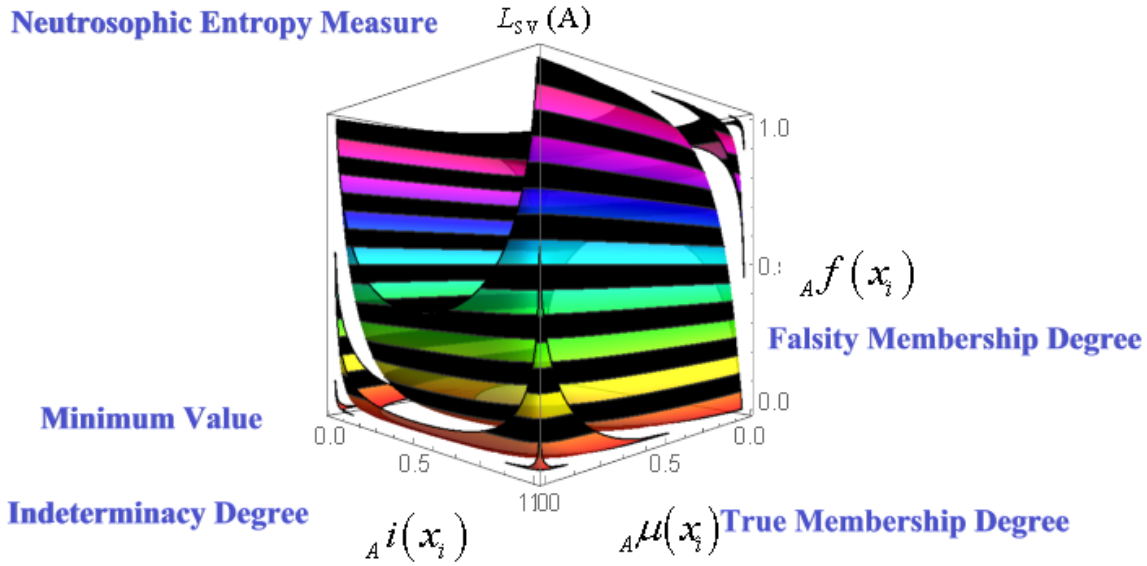


Figure 4. Neutrosophic entropy measure

The overall discussion in the outcoming theorems has brought us in a strong situation to apply the proposed measure (Figure 4) for discriminating the polyphenolic contents and antioxidant potentials of the *A. tortuosum* leaf extract.

2.5.3. Neutrosophic cross entropy-based methodology

Step 1. Normalization of Extracted Percentage Inhibitions of Various Assays

We first assume that the number of parameters (influencing factors) is "n". Also, "m". is the number of reaction sets. Let the maximum and minimum values of the percentage yields extracted using UAEM, SEM and MM as l_{max} and l_{min} respectively. To predict the highly efficient solvent needed for the extraction of polyphenolics, it is mandatory to normalize the percentage yields of each assay to be bounded in the interval [0, 1] which can be done by using the formula:

$$l^*=\frac{l-l_{min}}{l_{max}-l_{min}} \tag{17}$$

Step 2. Extracting upper and lower bounds for various antioxidant potentials and polyphenolic contents

Suppose the knowledge of percentage yield of the studied antioxidant potentials can be represented by the discrete set $A=(A_1,A_2,A_3,A_4)$. Also, the

knowledge of various known polyphenolic contents-TFC and TPC-can also be represented by the set $F=\left(F_{T_1},F_{T_2}\right)$

Let $U^*_{A_K}(x)(K=1,2,3,4)$ and $\mu^*_{A_K}(x)$ be the upper and lower bounds of the K^{th} assay. Define A_K as

$$A_K=\left\{<x,\left[\mu^*_{A_1}(x),U^*_{A_1}(x)\right]>,<x,\left[\mu^*_{A_2}(x),U^*_{A_2}(x)\right]>,...,<x,\left[\mu^*_{A_4}(x),U^*_{A_4}(x)\right]>\right\}$$

Define the set $F_{T_j}\left(j=1,2\right)$ as

$$F_{T_j}=\left\{<x,\left[\mu^*_{F_{T_1}}(x),U^*_{F_{T_1}}(x)\right]>,<x,\left[\mu^*_{F_{T_2}}(x),U^*_{F_{T_2}}(x)\right]>\right\}$$

Step 3. Extending Percentage Yield Interval into the Form of SVNSs

Let $f^*_{A_K}(x)=1-U^*_{A_K}(x)$ and $i^*_{A_K}(x)=1-f^*_{A_K}(x)-U^*_{A_K}(x)$ where $i^*_{A_K}(x)$ is restricted to $0\cdot01$ if it assumes any value less than $0\cdot001$. Then, $A_K\left(K=1,2,3,4\right)$ can be further extended into the following form:

$$A_K=\begin{Bmatrix}\left(<x,\mu^*_{A_1}(x),i^*_{A_1}(x),f^*_{A_1}(x)>\right),\left(<x,\mu^*_{A_2}(x),i^*_{A_2}(x),f^*_{A_2}(x)>\right),...,\\ \left(<x,\mu^*_{A_4}(x),i^*_{A_4}(x),f^*_{A_4}(x)>\right)\end{Bmatrix}$$

Similarly, the set F_{T_j} can also take the form of SVNSs as

$$F_{T_j}=\left\{\left(<x,\mu^*_{F_{T_1}}(x),i^*_{F_{T_1}}(x),f^*_{F_{T_1}}(x)>\right),\left(<x,\mu^*_{F_{T_2}}(x),i^*_{F_{T_2}}(x),f^*_{F_{T_2}}(x)>\right)\right\}$$

Step 4. Computing cross entropy values. The trigonometric SVNCE measure values between F_{T_j} and A_K can be found by substituting ${}_A\mu(x_i),{}_Ai(x_i),{}_Af(x_i);{}_B\mu(x_i),{}_Bi(x_i),{}_Bf(x_i)$ with $\mu^*_{A_K}(x),i^*_{A_K}(x),f^*_{A_K}(x);\mu^*_{F_{T_j}}(x),i^*_{F_{T_j}}(x),f^*_{F_{T_j}}(x)$ into (15). Thus,

$$\begin{aligned}L_{\text{SV}}(A_K,F_{T_j})(K=1,2,3,4;j=1,2)&=-18\tan1\\&+\left[\left(2+i^*_{A_K}(x)+i^*_{F_{T_j}}(x)\right)\tan\left(\frac{2+i^*_{A_K}(x)+i^*_{F_{T_j}}(x)}{2+2\sqrt{i^*_{A_K}(x_i)i^*_{F_{T_j}}(x_i)}}\right)+\left(4-i^*_{A_K}(x)-i^*_{F_{T_j}}(x)\right)\tan\left(\frac{4-i^*_{A_K}(x)-i^*_{F_{T_j}}(x)}{2+2\sqrt{\left(1-i^*_{A_K}(x_i)\right)\left(1-i^*_{F_{T_j}}(x_i)\right)}}\right)\right]\\&+\left[\left(2+f^*_{A_K}(x)+f^*_{F_{T_j}}(x)\right)\tan\left(\frac{2+f^*_{A_K}(x)+f^*_{F_{T_j}}(x)}{2+2\sqrt{f^*_{A_K}(x)f^*_{F_{T_j}}(x)}}\right)+\left(4-f^*_{A_K}(x)-f^*_{F_{T_j}}(x)\right)\tan\left(\frac{4-f^*_{A_K}(x)-f^*_{F_{T_j}}(x)}{2+2\sqrt{\left(1-f^*_{A_K}(x)\right)\left(1-f^*_{F_{T_j}}(x)\right)}}\right)\right]\end{aligned}$$

Step 5. Identification of the Most Efficient Solvent Based Upon Cross Entropy Values

Smaller value of $L_{\text{CE}}(A_K,F_{T_j})$ indicates that the antioxidant potential A_K is closer to the known polyphenolic content F_{T_j}.

3. Results and Discussion

3.1. Extract yield

The extract yield of different dry extracts was found in the range of 35.21-61.62% for 100 g of the powdered dry matter. The highest yield was shown by methanol extract, then by chloroform and hexane extracts that was contributed to the polarity of the solvent. Thus, the essence of methanol promoted the solubilization of secondary metabolites [21]. Furthermore, the yield varied for the extraction techniques with the best results for SEM followed by UAEM and substantially lower for MM. Comparable findings have also been recorded previously, where the maximum yield was demonstrated by different polar extracts obtained by SEM [22]. The Higher yields by employing SEM can be obtained via exhaustive extraction of plant material followed by repeated washing with a hot solvent [13]. Whereas, acoustic vibrations provide better results as compared to MM by raising the solubility and diffusion coefficients of secondary metabolites as well as lowering the viscosity of the solvent [19].

3.2. Antioxidant Assay

The polyphenolic compounds present in medicinal plants are referred as antioxidant agents and used as radical scavengers or metal chelators [23]. The antioxidant effect of the plant depends on phytochemicals present as both major and minor constituents that play an effective role in radical scavenging. The FRAP assay is based on using antioxidants for reducing the 2,4,6-tripyridyl-s-triazine – Fe(III) complex [21]. The FRAP values of these extracts ranged from 146.18 to 439.95 g DPE. The highest FRAP values were exhibited by all the extracts resulted by SEM while the lowest values were obtained for those obtained by MM. A comparable pattern has also been found in earlier studies for medicinal plant extracts [15]. Further, a maximum FRAP value was found for the methanol extract and a minimum for the hexane extracts. It is apparent from the current findings that the FRAP values are highly dependent on the type of solvent and the extraction methods used for the study.

ABTS assay involves scavenging the pre-generated $ABTS^{\bullet+}$ radical cation by the antioxidant [23]. The results showed that extracts in various solvents had various method-dependent scavenging potentials for radicals. Therefore, based on their IC50 value, the methanol extract obtained by SEM has been found to be most active in comparison with the other extracts. The leaf extract of *A. tortuosum* was found to exhibit significant DPPH scavenging activity with IC_{50} value maximum for methanol extract followed by chloroform extract and hexane extract. Therefore, the high antioxidant potential of the *A.tortuosum* leaf extract observed in this study signifies its ethno-medicinal usage to treat oxidative stress-related diseases [24].

3.3. Polyphenolic content

TPC is the quantitative approach to determine the extent of polyphenols present in the plant. Phenols are one of the important plant constituents as the radical scavenging ability depends on the hydroxyl group [14]. The phenolic groups are present in the secondary metabolites with redox properties that allow

them to function as a radical scavenger in various biotic activities such as antioxidant, antibacterial and antifungal [21]. TPC of *A. tortuosum* was also found to depend upon the nature of the extraction method and the solvent used. The extracts obtained by Soxhlet extraction exhibited the maximum amount, while the least amount was received by maceration. The methanol extract was found to provide the best yield of polyphenols.

Flavonoids, including flavanols and flavones, are secondary plant metabolites. These metabolites result in the colour of the plants as well as the antioxidant and antimicrobial activity depending upon the presence of -OH groups. Plant flavonoids exhibit antioxidant activity in both vivo and vitro studies [22]. The maximum yield of TFC for *A. tortuosum* leaf extract was obtained for the extracts obtained by Soxhlet extraction. Flavonoids exhibit more excellent solubility in polar solvents than non-polar solvents [21]. Hence, the methanol extract contained the highest TFC as compared to the other extracts [25]. Other researchers have also reported a significant amount of polyphenols in the tuber extract of *A. tortuosum* [17].

Table 1. Lower and upper bounds of each known antioxidant Potential, TPC and TFC of *A. tortuosum* leaf extract

Sets	**SEM**		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.997,1.000]	[0.995,1.000]	[0.994,1.000]
ABTS	[0.589,0.593]	[0.589,0.593]	[0.590,0.603]
FRAP	[0.464,0.468]	[0.461,0.465]	[0463,0.468]
TPC	[0.000,0.006]	[0.000,0.007]	[0.000,0.007]
TFC	[0.107,0.111]	[0.105,0.107]	[0.105,0.110]
	UAEM		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.998,1.000]	[0.989,1.000]	[0.986,1.000]
ABTS	[0.590,0.594]	[0.590,0.601]	[0.581,0.592]
FRAP	[0.462,0.469]	[0.464,0.474]	[0.447,0.465]
TPC	[0.000,0.003]	[0.000,0.006]	[0.000,0.012]
TFC	[0.110,0.114]	[0.107,0.114]	[0.106,0.114]
	MM		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.994,1.000]	[0.995,1.000]	[0.984,1.000]
ABTS	[0.585,0.591]	[0.592,0.605]	[0.580,0.591]
FRAP	[0.461,0.465]	[0.468,0.477]	[0.448,0.456]
TPC	[0.000,0.006]	[0.000,0.013]	[0.000,0.012]
TFC	[0.107,0.111]	[0.118,0.128]	[0.000,0.012]

3.4. Discrimination among antioxidant potential and polyphenolic content

The step-by-step procedure of the proclaimed methodology for the identification of the most effective solvent is already displayed in **Figure 1**. In the present case, we represent the various antioxidant potentials and polyphenolic contents extracted from the leaves and flowers of *Arisaema tortuosum* by the set $A=\left(A_1, A_2, A_3, A_4\right)$ where A_1 =DPPH radical scavenging A_2 = ABTS, A_3 = FRAP and the set $F_T=\left(F_{T_1}, F_{T_2}\right)$ where $F_{T_1}=$TPC and $F_{T_2}=$TFC, respectively.

Step 1. The lower and upper bounds of each known antioxidant potentials $A_K(K=1,2,3,4)$ and polyphenolic contents $F_{T_j}(j=1,2)$ can be extracted and represented in Table 1.

Step 2. Extending the percentage yield interval ranges of each known antioxidant potentials $A_K(K=1,2,3,4)$ and known polyphenolic contents $F_{T_j}(j=1,2)$ into the form of SVNSs and depicted in Table 2.

Table 2. Representation of extract yield interval range as SVNSs

Sets	**SEM**		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.997,0.003,0.000]	[0.995,0.005,0.000]	[0.994,0.006,0.000]
ABTS	[0.589,0.004,0.407]	[0.587,0.006,0.407]	[0.590,0.013,0.397]
FRAP	[0.464,0.004,0.532]	[0.461,0.004,0.535]	[0.463,0.003,0.534]
TPC	[0.000,0.006,0.994]	[0.000,0.007,0.993]	[0.000,0.007,0.993]
TFC	[0.107,0.004,0.889]	[0.105,0.002,0.893]	[0.105,0.005,0.890]
	UAEM		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.998,0.002,0.000]	[0.989,0.011,0.000]	[0.986,0.014,0.000]
ABTS	[0.590,0.004,0.406]	[0.590,0.011,0.399]	[0.581,0.011,0.408]
FRAP	[0.462,0.007,0.531]	[0.464,0.010,0.526]	[0.447,0.018,0.535]
TPC	[0.000,0.003,0.997]	[0.000,0.006,0.994]	[0.000,0.012,0.988]
TFC	[110,0.004,0.886]	[0.107,0.007,0.886]	[0.106,0.008,0.886]
	MM		
	Methanol	**Chloroform**	**Hexane**
DPPH	[0.994,0.006,0.000]	[0.995,0.005,0.000]	[0.984,0.016,0.000]
ABTS	[0.585,0.006,0.409]	[0.592,0.013,0.395]	[0.580,0.011,0.409]
FRAP	[0.461,0.004,0.535]	[0.468,0.009,0.523]	[0.448,0.008,0.544]
TPC	[0.000,0.006,0.994]	[0.000,0.013,0.987]	[0.000,0.012,0.988]
TFC	[0.107,0.004,0.889]	[0.118,0.010,0.872]	[0.000,0.012,0.988]

Step 3. The minimum cross entropy measure $L_{FS}^{\mu}(A_K, F_{T_1})$ values between various antioxidant potentials and TPC, for SEM, UAEM and MM, amount as 10.19, 9.99 and 10.04, respectively (Table 3). Similarly, The minimum cross entropy values $L_{FS}^{\mu}(A_K, F_{T_2})$ between various antioxidant potentials and TFC, for SEM, UAEM and

MM, amount as 1.96,1.88 and 4.45, respectively. These values indicate that the TFC followed by TPC are the most efficient solvents for extracting various antioxidant potentials viz FRAP, DPPH radical scavenging, TAC and NOS, respectively, extracted from the aerial parts of *Arisaema tortuosum* entropy measure based upon SVNSs. Furthermore, the minimum neutrosophic cross entropy measure $L_{SV}(A_K, F_{T_1})$ values between various antioxidant potentials and TPC, for SEM, UAEM and MM, amount as 16.98, 16.94 and 16.25, respectively (Table 4). Also, the minimum NCEM $L_{SV}(A_K, F_{2_1})$ values between various antioxidant potentials and TFC, for SEM, UAEM and MM, amount as 3.91, 3.78 and 7.56, respectively. These values also confirm that TFC followed by TPC are the most efficient solvents for extracting various antioxidant potentials.

Further, the best results were obtained for the Soxhlet extraction method followed by ultrasonication and maceration methods. The results reveal that the precision of the proposed methodology ranges from 86.60% to 173.21%/ , which justifies the accuracy of the proposed method.

Table 3. Fuzzy cross entropy value between each antioxidant potentials and TPC and TFC of *A. Tortuosum* leaf extract

Cross Entropy Values	SEM	UAEM	MM
$L^{\mu}_{FS}(A_1, F_{T_1})$	149.57	140.85	138.49
$L^{\mu}_{FS}(A_2, F_{T_1})$	16.74	16.63	16.55
$L^{\mu}_{FS}(A_3, F_{T_1})$	**10.19**	**9.99**	**10.04**
$L^{\mu}_{FS}(A_1, F_{T_2})$	35.21	31.56	62.99
$L^{\mu}_{FS}(A_2, F_{T_2})$	3.50	3.43	7.62
$L^{\mu}_{FS}(A_3, F_{T_2})$	**1.96**	**1.88**	**4.45**

Table 4. Neutrosophic cross entropy value between each antioxidant potentials and TPC and TFC of *A. Tortuosum* leaf extract

Neutrosophic Cross Entropy Values	SEM	UAEM	MM
$L_{SV}(A_1, F_{T_1})$	291.80	284.58	272.74
$L_{SV}(A_2, F_{T_1})$	27.70	27.73	26.55
$L_{SV}(A_3, F_{T_1})$	**16.98**	**16.94**	**16.25**
$L_{SV}(A_1, F_{T_2})$	97.86	92.59	145.92
$L_{SV}(A_2, F_{T_2})$	7.03	6.82	12.95
$L_{SV}(A_3, F_{T_2})$	**3.91**	**3.78**	**7.56**

5. Conclusion

The present study explores the use of a novel symmetric neutrosophic entropy measure for discrimination among antioxidant potential with TPC and TFC of *A. tortuosum* leaf extract obtained by using three different techniques viz UAE, SE and ME in presence of three solvents of different polarities (methanol, hexane and chloroform). The antioxidant potential was assessed through DPPH, ABTS and FRAP assay. The study revealed the impact of different solvents on the extraction of phytochemicals and antioxidant activity of *A. tortuosum*. The extracts possessed significant antioxidant activity due to high content of total polyphenols and flavonoids. However, the methanol extract was found to possess higher content of total polyphenols and flavonoids resulting in comparatively higher antioxidant activity. Similarly, SEM extraction was found to be more beneficial with best results. The quantitative analysis was carried out using neutrosophic cross-entropy based methodology. The studies confirmed a valid discrimination among TPC and TFC, DPPH, ABTS and FRAP parameters owing to high value of cross-entropy irrespective of the method of extraction used for the study. It shows that the antioxidant potential of the extract can be accredited to the rich TPC and TFC content. The study signifies that Soxhlet extraction method is the best method among the three methods for the phytochemical extraction from the medicinal plants.

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