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# Improving Decision-Making Under Uncertainty: A Comparative Study of Fuzzy Set Extensions

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## Abstract

Fuzzy sets have revolutionized decision-making by providing a mathematical tool for modeling uncertainty and imprecision. However, traditional fuzzy sets may not be sufficient in certain situations, leading to the development of extensions such as Type-2 fuzzy sets, Intuitionistic fuzzy sets, and Type-2 intuitionistic fuzzy sets. This paper provides an overview of these sets, comparing and contrasting them using operations of union, intersection, and distance measures. Additionally, a new distance measure is proposed for Type-2 intuitionistic fuzzy sets, which is demonstrated with a numerical example. Our novel distance measure proves to be the best tool for decision making problems containing uncertainty and the result is compared with the existing distance measures. By understanding the properties and applications of these fuzzy sets, informed decisions can be made in real-world situations with uncertainty and imprecision.

**Keywords: Fuzzy set, Type-2 Fuzzy set, Intuitionistic Fuzzy set, Type-2 Intuitionistic Fuzzy set, Distance measure**

# 1. Introduction

L.A. Zadeh [5] developed fuzzy set(FS) theory in response to the requirement to represent the activity of modelling in the human mind, which must take into account subjective and imprecise elements. Its key idea is membership grade(M-G), A member is either in or out of a subset according to conventional set theory. A proposition is either true or false in boolean logic. Information by its nature contains uncertainty, we make decisions in environments with various types of uncertainty in many scientific and industrial applications. Currently, the majority of decision-making procedures involve acquiring and processing information, much of which is noisy, fragmented, inconsistent, or all of the above. As a result, The models that explain the real world must be supplemented by appropriate uncertainty representations. With the introduction of soft computing approaches, many powerful tools in the field of computational intelligence, such as type-1 fuzzy logic, evolutionary algorithms, hybrid intelligent systems, and neural networks, were produced. [4, 24].

An extension of the ordinary FS, or type-1 fuzzy set(T1FS) is the (Type-2 fuzzy sets) T2FS. T2FSs could be referred to as a "fuzzy-fuzzy set" because the M-Gs are ambiguous and the domain of T2FSs is T1FS instead of crisp value. Zadeh [35, 36, 37] introduced the idea of T2FS. Mendel [23] provided overviews of T2FSs. Since T2FSs are a specific case of ordinary FSs and interval-valued fuzzy sets(IVFS), Takac [30] suggested that T2FSs are very useful in situations where there are more uncertainties. From the perspectives of type reduction and the centroid, Kundu et al.[17] gave a fixed charge transportation problem with type-2 fuzzy parameters. Both Dubois, Prade [6] and Mizumoto, Tanaka [19, 20] looked at the logical behaviour of T2FS. Later, a large number of scholars conducted extensive research on T2FS, theoretical and numerous application areas [12, 13, 15, 18].

The (intuitionistic fuzzy sets) IFS developed by Atanassov [2] that can be expressed in terms of the degrees of membership, and degree of non-membershipis a more generalised variant of the FS. The study of problems like decision-making by utilising IFSs, however has attracted more attention [25]. In order to address the issue of students satisfaction with university instruction, Marasini et al. [27] used an IFS technique that may take into consideration two sources of uncertainty: one connected to items and the other to subjects. Dan et al.[10] Present the generalised (Type-2 intuitionistic fuzzy set) T2IFS, whose type-1 membership is the conventional fuzzy membership and whose type-2 comprises both membership and non-membership as the IFS. Singh.S and Garg.H [28] proposed a multi criteron decision making problem by providing a distance measure for T2IFS. Some t-conorm-based distance measures and knowledge measures for Pythagorean fuzzy sets with their application in decision-making was given by Ganai. A. H.[42]. A Multicriteria decision-making based on distance measures and knowledge measures of Fermatean fuzzy sets given by Ganie. A. H. [40]. A Generalized hesitant fuzzy knowledge measure with its application to multi-criteria decision-making is given by Singh, S. and Ganie, A. H. [41]. Almulhim, T. and Barahona, I. [43] gave an extended picture fuzzy multicriteria group decision analysis with different weights: A case study of COVID-19 vaccine allocation.

Fuzzy sets have transformed decision making by providing a mathematical tool for modeling uncertainty and imprecision. However, traditional fuzzy sets may not be adequate in certain situations, leading to the development of type-2 fuzzy sets, which introduce a third dimension to membership functions to allow for more precise definitions of uncertainty. Different extensions of fuzzy sets exist to make them more manageable, and understanding their properties is crucial for selecting the most suitable set for specific conditions. T1FS, T2FS, IFS, and T2IFS are sets examined for their properties, with numerical examples provided for comparison. Furthermore, a new distance measure is proposed for T2IFSs, demonstrating its significance with an example. By grasping the diverse properties and applications of these fuzzy sets, informed decisions can be made in real-world situations with uncertainty and imprecision.

This paper is divided into several sections to help you understand and compare different existing fuzzy sets. In section **??**, we'll cover the preliminaries and basic concepts to give you a solid foundation. Then in section 3 , we'll compare different fuzzy sets using the operations of union and intersection. We'll explore their similarities and differences, helping you make informed decisions for your specific needs. section 4 proposes a new distance measure for T2IFS, accompanied by a numerical example to compare the results. Finally, in section 5, we'll draw our conclusions and tie it all together.

# 2. Preliminaries and Basic Concepts

## 2.1. Fuzzy set (FS)

**Definition 1.** *[33] A FS J in S is a set of an ordered pair if S is a collection of elements denoted generally by s:*

$$J = \{(s, \mu_J(s))|s \in S\} \tag{1}$$

*where $\mu_J(s)$ is called M-F of FS J in S and its value lies in between closed interval $[0,1]$.*

## 2.2. Operation on Fuzzy sets

The following operations for FSs are defined by [33] as generalisations of crisp sets and crisp statements in his first paper.

**Definition 2.** *Intersection [logical and]: The following M-F is used to describe the intersection of the FSs J and K*

$$\mu_{J\cap K}(s) = Min\{(\mu_J(s), \mu_K(s))\forall s \in S \tag{2}$$

**Definition 3.** *Union [exclusive or]: The union's M-F is described as*

$$\mu_{J\cup K}(s) = Max\{(\mu_J(s), \mu_K(s)) \ \ \forall s \in S \tag{3}$$

**Definition 4.** *Complement (negation): The following is a definition of the complement's membership function:*

$$\mu_J(s) = 1 - \mu_J(s) \ \ \forall s \in S \tag{4}$$

Later, the above defined definitions were expanded. Both the "logical and" (intersection) and the "inclusive or" (union) can be modelled as t-norms [3, 8, 9, 11, 16, 22, 32, 39]. Both kinds are associative, commutative, and monotonic. Below is a compilation of typical dual pairs of nonparameterized t-norms and t-conorms:

**Definition 5.** *Drastic product:*

$$t_W(\mu_J(s), \mu_K(s)) = \begin{cases} Min\{(\mu_J(s), \mu_K(s))\} & if \;\; Max\{(\mu_J(s), \mu_K(s))\} = 1 \\ 0 & otherwise\} \end{cases} \tag{5}$$

**Definition 6.** *Drastic sum:*

$$S_W(\mu_J(s), \mu_K(s)) = \begin{cases} Max\{(\mu_J(s), \mu_K(s))\} & if \;\; Min\{(\mu_J(s), \mu_K(s))\} = 0 \\ 1 & otherwise\} \end{cases} \tag{6}$$

**Definition 7.** *Bounded difference:*

$$t_1(\mu_J(s), \mu_K(s)) = Max\{0, \mu_J(s) + \mu_K(s) - 1\} \tag{7}$$

**Definition 8.** *Bounded sum:*

$$s_1(\mu_J(s), \mu_K(s)) = Min\{1, \mu_J(s) + \mu_K(s)\} \tag{8}$$

**Definition 9.** *Einstein product:*

$$t_{1.5}(\mu_J(s), \mu_K(s)) = \frac{\mu_J(s) \cdot \mu_K(s)\}}{2 - [\mu_J(s) + \mu_K(s) - \mu_J(s) \cdot \mu_K(s)]} \tag{9}$$

**Definition 10.** *Einstein sum:*

$$s_{1.5}(\mu_J(s), \mu_K(s)) = \frac{\mu_J(s) + \mu_K(s)\}}{1 + \mu_J(s) + \mu_K(s)} \tag{10}$$

**Definition 11.** *Hamachar product:*

$$t_{2.5}(\mu_J(s), \mu_K(s)) = \frac{\mu_J(s) \cdot \mu_K(s)\}}{\mu_J(s) + \mu_K(s) - \mu_J(s) \cdot \mu_K(s)} \tag{11}$$

**Definition 12.** *Hamachar sum:*

$$s_{2.5}(\mu_J(s), \mu_K(s)) = \frac{\mu_J(s) + \mu_K(s) - 2\mu_J(s) \cdot \mu_K(s)\}}{1 - \mu_J(s) \cdot \mu_K(s)} \tag{12}$$

**Definition 13.** *Minimum:*

$$t_3(\mu_J(s), \mu_K(s)) = min\{\mu_J(s), \mu_K(s)\} \tag{13}$$

**Definition 14.** *Maximum:*

$$s_3(\mu_J(s), \mu_K(s)) = max\{\mu_J(s), \mu_K(s)\} \tag{14}$$

The above defined operators have been ordered as follows:

$$t_w \leq t_1 \leq t_{1.5} \leq t_2 \leq t_{2.5} \leq t_3 \tag{15}$$

$$s_3 \leq s_{2.5} \leq s_2 \leq s_{1.5} \leq s_1 \leq s_w \tag{16}$$

The operations defined above are not valid for T2FSs because T2FSs contain type-2 membership function so extension principle is defined to deal with the operations for T2FSs.

## 2.3. Type-2 Fuzzy set (T2FS)

**Definition 15.** *T2FS [21] is defined as the extension of ordinary FS that is T1FS and is characterised by Type-2 membership function $\mu_{\bar{Z}}(s,u)$. Let S be a fixed universe a T2FS $\bar{Z} \subseteq S$ is defined mathematically as*

$$\bar{Z} = (s, u, \mu_{\bar{Z}}(s,u)) \ \ |s \in S, u \in j_s \subseteq [0,1]$$

*in which $0 \leq \mu_{\bar{Z}}(s,u) \leq 1$. It can also be written as*

$$\bar{Z} = \int_{s \in S} \mu_{\bar{Z}}(s)/s \quad |s \in S, u \in j_s \subseteq [0,1] = \int_{s \in S} [\int_{u \in j_s} (g_s(u)/u)]/s$$

*Where $\mu_{\bar{Z}}(s) = \int_{u \in j_s} (g_s(u)/u)$ is the grade of membership,$g_s(u) = \mu_{\bar{Z}}(s,u)$ is named as secondary membership function(S-MF) where $u$ is primary membership function(P-MF) of $\bar{Z}$ and $j_s$ is called P-MF of S.*

**Definition 16.** *Footprint of Uncertainty(FOU) [26] actually for T2FS we are having 3-D structure which becomes very difficult for calculation so we take the base of 3rd dimension to calculate the values which is called FOU. It can be defined as the union of all P-MF that is*

$$FOU(Z) = \cup_{s \in S}(j_s) \tag{17}$$

**Example 1.** *Let "Young" be the set defined by T2FS $\bar{E}$ and the P-MF of $\bar{E}$ be "Youthness„ and S-MF be degree of "Youthness". Let $T = \{7, 9, 13\}$ be the car set having primary membership at point $T$ respectively. $j_7 = \{0.7, 0.8, 0.9\}, j_9 = \{0.5, 0.6, 0.7\}$ and $j_{13} = \{0.3, 0.4, 0.5\}$ then S-MF of point 7 is $\bar{\mu}_{\bar{E}}(7,u) = \{(0.8/0.7) + (0.6/0.8) + (0.5/0.9)\}$ that is $\bar{\mu}_{\bar{E}}(7, 0.7) = 0.8$ is the secondary membership grade of 7 with respect to 0.7 similarlaly $\bar{\mu}_{\bar{E}}(9,u) = \{(0.7/0.5) + (0.6/0.6) + (0.5/0.7)\}$ and $\bar{\mu}_{\bar{E}}(13,u) = \{(0.8/0.3)+(0.7/0.4)+(0.4/0.5)\}$ then discrete T2FS can be defined accordingly $\bar{E} = \{(0.8/0.7)+(0.6/0.8)+(0.5/0.9)\}/7 + \{(0.7/0.5) + (0.6/0.6) + (0.5/0.7)\}/9 + \{(0.8/0.3) + (0.7/0.4) + (0.4/0.5)\}/13$*

**Definition 17.** *Extension Principle : The extension principle is one of the most fundamental ideas in FS theory that can be used to apply clear mathematical ideas to FSs. It was already suggested in Zadeh's initial contribution in its simplest form. Modifications have been suggested in the interim. Zadeh, Dubois, and Prade [25, 27, 28] provided the following definition of the extension principle:*

*Let $E_1, E_2..., E_r$ be r fuzzy sets in $S_1, S_2..., S_r$ and S be the Cartesian product of universes S $= S_1 \times ..., \times S_r$, respectively. , where f is a mapping from S to a universe T. t $= f(s_1, ..., s_r)$. We can then define a fuzzy set F in T by using the extension principle concept*

$$\bar{F} = \{t, \mu_{\bar{F}}(t) | t = f(s_1, ..., s_r), (s_1, ..., s_r) \in S\} \tag{18}$$

$$\mu_{\bar{F}}(t) = \begin{cases} \{sup_{(s_1,...,s_r) \in f^{-1}(t)} min\{\mu_{\bar{E}_1(s_1)}, ..., \mu_{\bar{E}_r(s_r)}\} \\ if \quad f^{-1}(t) \neq 0 \\ 0 & otherwise\} \end{cases} \tag{19}$$

*Where $f^{-1}$ is the inverse of f*

*if we put r=1 then the extension principle is reduced to*

$$\bar{F} = \{f(\bar{E}) = \{(t, \mu_{\bar{F}}(t)) | t = f(s), s \in S\} \tag{20}$$

*where*

$$\mu_{\bar{F}}(t) = \begin{cases} \{sup_{(s) \in f^{-1}(t)} min\{\mu_{\bar{E}(s)}\} & if \quad f^{-1}(t) \neq 0 \\ 0 & otherwise\} \end{cases} \tag{21}$$

## 2.4. Intuitionistic Fuzzy set

**Definition 18.** *An IFS is a set which is having both a M-F and a N-MF, as opposed to a classical fuzzy set, which only has a M-F. An object of the form is what Atanassov [1] defines as an IFS J in S.*

$$J = \{s, \mu_J(s), \nu_J(s) : s \in S, \mu_J(s) \in [0, 1], \nu_J(s) \in [0, 1]\} \tag{22}$$

*where as $\mu_J(s) : S \to [0, 1]$ and $\nu_J(s) : S \to [0, 1]$ is called as degree of membership and degree of non-membership respectively such that $0 \leq \mu_J(s) + \nu_J(s) \leq 1 \forall s \in S$*

**Example 2.** *Let "Young" be the set defined by IFS J. The degree of "Youthness" and "Adultness" are membership and non-membership respectively. Let $T = \{11, 14, 16\}$ and the M-G of the point $11$ be $\mu_P(12) = \{0.7, 0.8, 0.9\}$ and the non-membership grade(N-MG) of point $11$ is $\nu_P(11) = \{0.1, 0.2, 0.0\}$ similarly $\mu_P(14) = \{0.5, 0.6, 0.7\}, \nu_P(14) = \{0.4, 0.3, 0.1\}$ and $\mu_P(16) = \{0.4, 0.5, 0.6\}, \nu_P(16) = \{0.5, 0.4, 0.2\}$*

## 2.5. Type 2 intuitionistic Fuzzy set(T2IFS)

**Definition 19.** *[28] A T2IFS J in the universe of discourse S is set of pairs $\{s, \mu_J(s), \nu_J(s)\}$ where s is the element of T2IFS, $\mu_J(s)$ and $\nu_J(s)$ are called grades of the membership and non-membership respectively* *defined in the interval [0,1] as*

$$\mu_J(s) = \int_{s\in j_s^1} (g_s(u)/u), \quad \nu_J(s) = \int_{s\in j_s^2} (h_s(v)/v) \tag{23}$$

*Where $g_s(u)/u$ and $h_s(v)/v$ are termed as S-MF and secondary non-membership function(S-NMF). In addition $\mu_J$,$\nu_J$ denotes the P-MF and primary non-membership functions (P-NMF) and $j_{s^1}$ and $j_{s^2}$ are named as the P-MF and P-NMF of S, respectively. In other words, T2IFS J is defined in the universe of discourse as*

$$J = \{(s, u_J, v_J), g_{sj}(u_J), h_{sj}(v_J) | s \in S, u_J \in j_{s^1}, v_J \in j_{s^2}\} \tag{24}$$

*Where the element of the domain $(s, (u_J, v_J))$ called as P-MF $(u_J)$ and P-NMF $(v_J)$ of $s \in S$ where $g_{sj}(u_J)$ and $h_{sj}(v_J)$ S-MF and S-NMF respectively.*

# 3. Comperative analysis on different types of fuzzy sets

## 3.1. Comparison on the basis of operation

In order to make comparison we take few fuzzy sets into account, ordinary FS or T1FS, T2FS, IFS and T2IFS we define union and intersection for these defined sets

## 3.2. Union and Intersection for T1FS

let J and K be two fuzzy sets then their union and intersection is defined as follows

### Union:

$J \cup K = max\{\mu_J(s), \mu_K(s)\}$
where $\mu_J(s)$ and $\mu_K(s)$ are the membership values of FS J and K.

**Example 3.** *Let J={s,0.8} and K={s,0.7} then* $J \cup K = max\{0.8, 0.7\} \implies J \cup K = 0.8$

### Intersection:

$J \cap K = min\{\mu_J(s), \mu_K(s)\}$
where $\mu_J(s)$ and $\mu_K(s)$ are the membership values of FS J and K.

**Example 4.** *Let J={s,0.8} and K={s,0.7} then* $J \cup K = min\{0.8, 0.7\} \implies J \cap K = 0.7$

## 3.3. Union and intersection for T2FS

Let $\mu_J$ and $\mu_K$ are two T2FS

## Intersection:

$\mu_J = \{s, \mu_J(s)\}$ and $\mu_K = \{s, \mu_K(s)\}$
where $\mu_J(s) = \{u_i, \mu_{ui}(s)\}$
$\mu_K(s) = \{v_j, \mu_{vj}(s)\}$
by extension principle intersection is defined as

$$\mu_{J\cap K}(s) = \{z, \mu_{J\cap K}(z) | \ z = \min\{u_i, v_j\}\} \tag{25}$$

where $\mu_{J\cap K}(z) = \sup_{z=\min(u_i,v_j)} \min\{\mu_{ui}, \mu_{vj}\}$.

## Union:

$$\mu_{J\cup K}(s) = \{z, \mu_{J\cup K}(z) | \ z = \max\{u_i, v_j\}\} \tag{26}$$

where $\mu_{J\cup K}(z) = \sup_{z=\max(u_i,v_j)} \min\{\mu_{ui}, \mu_{vj}\}$.

**Example 5.** *Let J be a small integer and K be an integer. Find $\mu_{J\cap K}(s)$ at s=3*

*Table 1*

| $i$ | $u_i$ | $\mu_{ui}$ | $v_j$ | $\mu_{vj}$ |
|---|---|---|---|---|
| 1 | 0.8 | 1 | 1 | 1 |
| 2 | 0.7 | 0.5 | 0.8 | 0.5 |
| 3 | 0.6 | 0.4 | 0.7 | 0.3 |

$J = \{s, \mu_J(s)\}$ *at s=3*
$\mu_J(s) = \{(u_1, \mu_{u1}), (u_2, \mu_{u2}), (u_3, \mu_{u3})\}$
*={(0.8,1), (0.7,0.5), (0.6,0.4)}*
*similarly*
$\mu_K(s) = \{(v_1, \mu_{v1}), (v_2, \mu_{v2}), (v_3, \mu_{v3})\}$
*={(1,1), (0.8,0.5), (0.7,0.3)}*


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*Table 2*

| $u_i$ | $v_j$ | $\min(u_i, v_j)$ | $\mu_{ui}(3)$ | $\mu_{vj}(3)$ | $\min(\mu_{ui}(3), \mu_{vj}(3))$ |
|---|---|---|---|---|---|
| 0.8 | 1 | 0.8 | 1 | 1 | 1 |
| 0.8 | 0.8 | 0.8 | 1 | 0.5 | 0.5 |
| 0.8 | 0.7 | 0.7 | 1 | 0.3 | 0.3 |
| 0.7 | 1 | 0.7 | 0.5 | 1 | 0.5 |
| 0.7 | 0.8 | 0.7 | 0.5 | 0.5 | 0.5 |
| 0.7 | 0.7 | 0.7 | 0.5 | 0.3 | 0.3 |
| 0.6 | 1 | 0.6 | 0.4 | 1 | 0.4 |
| 0.6 | 0.8 | 0.6 | 0.4 | 0.5 | 0.4 |
| 0.6 | 0.7 | 0.6 | 0.4 | 0.3 | 0.3 |

$\mu_{J\cap K}(s) = \sup_{z=0.8}\{1, 0.5\} = 1$
$\sup_{z=0.7}\{0.3, 0.5, 0.5, 0.3\} = 0.5$
$\sup_{z=0.6}\{0.4, 0.4, 0.3\} = 0.4$

## 3.4. Union and Intersection for IFS

let J and K be two IFSs then we define

## Union:

$$J \cup K = \max\{\mu_J(s), \mu_K(s)\}, \min\{\nu_J(s), \nu_K(s)\} \tag{27}$$

## Intersection:

$$J \cap K = \min\{\mu_J(s), \mu_K(s)\}, \max\{\nu_J(s), \nu_K(s)\} \tag{28}$$

**Example 6.** *Let we have two IFS defined as*
*J={s,0.6,0.4} and K={s,0.7,0.2} then*

$$J \cup K = \max\{0.6, 0.7\}, \min\{0.4, 0.2\} = \{0.7, 0.2\}$$

## 3.5. Union and Intersection for T2IFSs

lets consider two T2IFS J and K

$$J = \int_{s\in S} \left( \int_{u\in i_s^u} (\mu_J(s,u), \nu_J(s,u))/u \right) /S$$

and

$$K=\int_{s\in S}\left(\int_{v\in i_s^v}(\mu_K(s,v),\nu_K(s,v))/v\right)/S$$

where $i_s^u\subseteq[0,1]$ and $i_s^v\subseteq[0,1]$ are domains for S-MF respectively. Then we define union for J and K as:

$$J\cup K=\int_{s\in S}\frac{\frac{\left(\int_{v\in i_s^w}(\mu_{J\cup K}(s,w),\nu_{J\cup K}(s,w)\right)}{w}}{S},i_s^u\cup i_s^v=i_s^w\subseteq[0,1]$$

where

$$\mu_{J\cup K}(s)=\phi\left(\int_{u\in i_s^u}(\mu_J(s,u))/u,\int_{v\in i_s^v}(\mu_K(s,v))/v\right)$$

by using extension principle, we obtain

$$\mu_{J\cup K}(s,w)=\int_{u\in i_s^u}\int_{v\in i_s^v}\left(\mu_J(s,u)\wedge\mu_K(s,u)\right)/\phi(u,v),$$

where $\phi(u,v)$ is t-conorm of u and v

$$\mu_{J\cup K}(s,w)=\int_{u\in i_s^u}\int_{v\in i_s^v}\left(\mu_J(s,u)\wedge\mu_K(s,u)\right)/(u\vee v),$$

similarly

$$\nu_{J\cup K}(s,w)=\int_{u\in i_s^u}\int_{v\in i_s^v}(\nu_J(s,u)\vee\nu_K(s,u))/(u\vee v),$$

Intersection for J and K is defined as:

$$J\cap K=\int_{s\in S}\frac{\frac{\left(\int_{v\in i_s^w}(\mu_{J\cap K}(s,w),\nu_{J\cap K}(s,w))\right)}{w}}{S},i_s^u\cup i_s^v=i_s^w\subseteq[0,1]$$

where

$$\mu_{J\cap K}(s,w)=\int_{u\in i_s^u}\int_{v\in i_s^v}(\mu_J(s,u)\wedge\mu_K(s,u))/(u\wedge v),$$

and

$$\nu_{J\cap K}(s,w)=\int_{u\in i_s^u}\int_{v\in i_s^v}(\nu_J(s,u)\vee\nu_K(s,u))/(u\wedge v),$$

**Example 7.** *Let J and K be two T2IFSs representing the set "Young". The "Youthness" is P-MF of J and K. Then the degree of "Youthness" and "Adultness" are the S-MF and S-NMF respectively. We consider both J and K to be defined on S={7,9,13} which are eventyualy represented as:*

*J=((0.8,0.1)/0.7 +(0.6,0.2)/0.8 + (0.5,0.4)/0.9) /7 + ((0.7,0.2)/0.5 + (0.6,0.3) /0.6 +(0.5,0.4)/0.7) /9 +((0.8,0.2)/0.3 +(0.7,0.3)/0.4 +(0.4,0.5)/0. 5)/13*

*K= ((0.7,0.2)/0.6 +(0.5,0.4)/0.7 +(0.5,0.5)/0.8)/7 + ((0.8,0.2)/0.4 +(0.8,0.1)/0.5 +(0.4,0.5)/0.6)/9 +((0.7,0.3)/0.2 +(0.6,0.3)/0.3 +(0.4,0.4)/0.4)13.*

*Now for 7, S-M and S-NM of J and K are*

*((0.8,0.1)/0.7 +(0.6,0.2)/0.8 +(0.5,0.4)/0.9)/7*

*and*

*((0.7,0.2)/0.6 +(0.5,0.4)/0.7 +(0.5,0.5)/0.8)/7*

*for S=7, the union of J and K is* $(\mu_{J\cup K}(7), \nu_{J\cup K}(7))$

*((0.8,0.1)/0.7 +(0.6,0.2)/0.8 +(0.5,0.4)/0.9)/7* $\vee$ *((0.7,0.2)/0.6 +(0.5,0.4)/0.7 + (0.5,0.5)/0.8)/7* $((0.8 \wedge 0.7), (0.1 \vee 0.2))/(0.7 \vee 0.6)$ $+((0.8 \wedge 0.5), (0.1 \vee 0.4))/(0.7 \vee 0.7)$ $+((0.8 \wedge 0.5), (0.1 \vee 0.5))/(0.7 \vee 0.8)+$ $+((0.6 \wedge 0.7), (0.2 \vee 0.2))/(0.8 \vee 0.6)$ $+((0.6 \wedge 0.5), (0.2 \vee 0.4))/(0.8 \vee 0.7)$ $+((0.6 \wedge 0.5), (0.2 \vee 0.5))/(0.8 \vee 0.8)$ $+((0.5 \wedge 0.7), (0.4 \vee 0.2))/(0.9 \vee 0.6)$ $+((0.5 \wedge 0.5), (0.4 \vee 0.4))/(0.9 \vee 0.7)$ $+((0.5 \wedge 0.5), (0.4 \vee 0.5))/(0.9 \vee 0.8)$

*=(0.5,0.4)/0.7 + (0.5,0.5)/0.8 + (0.6,0.2)/0.8 +(0.5,0.4)/0.8 +(0.5,0.5)/0.8 +(0.5,0.4)/0.9 +(0.5,0.4)/0.9 + (0.5,0.5)/0.9*

*= (0.5,0.4)/0.7+*(max*(0.5,0.6,0.5,0.5),* min*(0.5,0.2,0.4,0.5)) 0.8 +*

(max*(0.5,0.5,0.5),*min*(0.4,0.4,0.5))/0.9*

*=(0.5,0.4)/0.7 + (0.6,0.2)/0.8 + (0.5,0.4)/0.9*

## Analysis on operations of union and intersection for different fuzzy sets

Fuzzy sets use a membership function to assign a degree of membership to each element of a set. This allows for a more flexible and nuanced representation of uncertainty than the binary membership characteristic of classical sets. The union and intersection operations of fuzzy sets are defined by taking the maximum and minimum of the membership functions, respectively.

Type-2 fuzzy sets take this idea one step further, by allowing the membership function itself to be a fuzzy set. This enables an even more sophisticated representation of uncertainty, but also makes the union and intersection operations more complex.

Intuitionistic fuzzy sets go beyond the binary membership characteristic of fuzzy sets and also incorporate a degree of non-membership. This allows for a more nuanced representation of uncertainty, particularly when dealing with vague or ambiguous information. The union and intersection operations of intuitionistic fuzzy sets take into account both membership and non-membership degrees.

Type-2 intuitionistic fuzzy sets combine the concepts of T2FS and IFS, allowing for an even more sophisticated representation ofOverall, these set types offer a rich and powerful toolbox for dealing with uncertainty and imprecision in a wide range of applications, including decision making, data analysis, and control systems. uncertainty. The union and intersection operations of T2IFSs also take into account both membership and non-membership degrees, making them particularly useful for handling uncertain or ambiguous information.

## Results of Comparison

As we compared different fuzzy sets on the basis of union and intersection every fuzzy set has their importance, but we found that type-2 intuitionistic fuzzy sets offer a best tool for solving decision making problems. In terms of operations, type-2 intuitionistic fuzzy sets exhibit differences compared to other fuzzy sets. The union and intersection operations for type-2 intuitionistic fuzzy sets involve considering the lower and upper membership and non-membership values separately. This allows for a more flexible and granular manipulation of fuzzy sets, enabling decision-makers to capture the various degrees of uncertainty and ambiguity inherent in complex decision problems.

## 3.6. Comparison on the basis of distance measures

## Distance measure between FSs and T2FSs

**Definition 20.** *Distance measure plays an important role in decision making. Let* $F_1(S)$ *be the class of all T1FS of S.* $\mu_J(s) \to [0,1]$*is the M-F of S in* $F_1(S)$*. Let's consider two FSs J and K in* $F_1(S)$*. Then d(J,K) is said to be a distance measure between J and K if*

$$d\colon F_1(S) \times F_1(S) \to [0,1] \tag{29}$$

*satisfies following axioms.*

$$(p1) \quad 0 \le d(J,K) \le 1 \ \forall \ J,K \in F_1(S) \tag{30}$$

$$(p2) \quad d(J,K) = d(K,J) \tag{31}$$

$$(p3) \quad d(J,K) = 0 \quad if \ J = K \tag{32}$$

$$(p4) \quad d(J,K) = 0, d(J,L) = 0, L \in F_1(S) \ \textit{ then } \ d(K,L) = 0. \tag{33}$$

For two FSs J and K, the following distance measure is provided. [14]

Hamming distance

$$d_{1h}(J,K) = \frac{1}{n}\sum_{j=1}^{n} |\mu_J(s_j) - \mu_K(s_j)| \tag{34}$$

Euclidian distance

$$d_{1e}(J,K) = \{\frac{1}{n}\sum_{j=1}^{n} |\mu_J(s_j) - \mu_K(s_j)|^2\}^{1/2} \tag{35}$$

## 3.7. Numerical Example

Lets consider four kinds of metal fields and each field is featured by five metals . We can express these four fields by FSs $\{c_1, c_2, c_3, c_4\}$ in space $\{S = s_1, s_2, s_3, s_4, s_5\}$.See Table 3. There is another kind of special metal $\{n\}$ so we have to find which metal field this metal belongs.

Table 3

| | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ |
|---|---|---|---|---|---|
| $u_{c_1}(s)$ | 1 | 0.7 | 0.5 | 0.7 | 1 |
| $u_{c_2}(s)$ | 1.0 | 0.7 | 0.9 | 0.9 | 0.9 |
| $u_{c_3}(s)$ | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 |
| $u_{c_4}(s)$ | 0.9 | 0.9 | 0.9 | 0.2 | 0.7 |
| $u_n(s)$ | 0.9 | 0.2 | 0.2 | 0.2 | 0.9 |

we have

$$d_{1h}(J, K) = \frac{1}{5}\sum_{j=1}^{5} |\mu_J(s_j) - \mu_K(s_j)| \tag{36}$$

since from the Table 3 and using $d_{1h}(J, K)$ we get following result

$d_{1h}(c_1, n) = 0.3, d_{1h}(c_2, n) = 0.4, d_{1h}(c_3, n) = 0.575, d_{1h}(c_4, n) = 0.32$

which implies special metal n is produced from metal field $c_1$

for T1FS we have only M-F but for T2FS we have P-MF,S-MF and FOU.

[29] Examine the following factors in order to calculate the distance measure for T2FSs. P-MF, S-MF and FOU in the currently used distance measure the following distance measure is defined for type-2 fuzzy sets J and K.

$$d_{2h}(J, K) = \frac{1}{2n}\sum_{j=1}^{n} |u_J(s_j) - u_K(s_j)| + |f_{sj}(u_J) - f_{sj}(u_k)| + |\xi_J(s_j) - \xi_K(s_j)| \tag{37}$$

## 3.8. Numerical Example

Let's consider four kinds of metal fields and each field is featured by five metals . We can express these four fields by T2FSs $\{c_1, c_2, c_3, c_4\}$ in space $\{S = s_1, s_2, s_3, s_4, s_5\}$.See Table 3. There is another kind of special metal $\{n\}$ so we have to find which metal field this metal belongs.

Table 4

| | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ |
|---|---|---|---|---|---|
| $u_{c_1}(s)$ | 1 | 0.7 | 0.5 | 0.7 | 1 |
| $f_s(u_{c_1})$ | 0.7 | 0.9 | 0.2 | 0.5 | 0.9 |
| $u_{c_2}(s)$ | 1.0 | 0.7 | 0.9 | 0.9 | 0.9 |
| $f_s(u_{c_2})$ | 0.9 | 0.7 | 1.0 | 0.7 | 0.7 |
| $u_{c_3}(s)$ | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 |
| $f_s(u_{c_3})$ | 0.7 | 1.0 | 0.9 | 0.9 | 0.4 |
| $u_{c_4}(s)$ | 0.9 | 0.9 | 0.9 | 0.2 | 0.7 |
| $f_s(u_{c_4})$ | 1.0 | 0.7 | 0.5 | 0.0 | 0.4 |
| $u_n(s)$ | 0.9 | 0.2 | 0.2 | 0.2 | 0.9 |
| $f_s(u_n)$ | 0.4 | 0.5 | 0.4 | 0.0 | 0.7 |

we have

$$d_{2h}(J,K) = \frac{1}{2n}\sum_{j=1}^{n} |u_J(s_j) - u_K(s_j)| + |f_{sj}(u_J) - f_{sj}(u_k)| + |\xi_J(s_j) - \xi_K(s_j)| \tag{38}$$

since from the Table 4 and using $d_{2h}(J,K)$ we get following result
$d_{2h}(c_1,n) = 0.44, d_{2h}(c_2,n) = 0.48, d_{2h}(c_3,n) = 0.6, d_{2h}(c_4,n) = 0.46$
which implies special metal n is produced from metal field $c_1$.

## Distance measures between IFS

**Definition 21.** *Some new distance measures between IFSs has been defined By [39] Let J and K be two IFS in* $S = \{s_1, s_2, ...s_n\}$

$$d_3(J,K) = \frac{1}{n}\sum_{i=1}^{n} \frac{|\mu_J(s_i) - \mu_K(s_i)| + |\nu_J(s_i) - \nu_K(s_i)|}{4} + \frac{max(|\mu_J(s_i) - \mu_K(s_i)|, |\nu_J(s_i) - \nu_K(s_i)|)}{2} \tag{39}$$

$where J = \{s_i, \mu_J(s_i), \nu_J(s_i)|s_i \in S\}, K = \{s_i, \mu_K(s_i), \nu_K(s_i)|s_i \in S\}$

## 3.9. Numerical Example

Lets consider four kinds of metal fields and each field is featured by five metals . We can express these four fields by T2IFSs $\{c_1, c_2, c_3, c_4\}$ in space $\{S = s_1, s_2, s_3, s_4, s_5\}$.See Table 5. There is another kind of special metal $\{n\}$ so we have to find which metal field this metal belongs.

Table 5

| | $x_1$ | $x_2$ | $x_3$ | $x_4$ | $x_5$ |
|---|---|---|---|---|---|
| $u_{c_1}(x)$ | 1 | 0.7 | 0.5 | 0.7 | 1 |
| $v_{c_1}(x)$ | 0 | 0.1 | 0.4 | 0.2 | 0 |
| $u_{c_2}(x)$ | 1.0 | 0.7 | 0.9 | 0.9 | 0.9 |
| $v_{c_2}(x)$ | 0 | 0.4 | 0.1 | 0.1 | 0.1 |
| $u_{c_3}(x)$ | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 |
| $v_{c_3}(x)$ | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 |
| $u_{c_4}(x)$ | 0.9 | 0.9 | 0.9 | 0.2 | 0.7 |
| $v_{c_4}(x)$ | 0.1 | 0.0 | 0.1 | 0.7 | 0.2 |
| $u_n(x)$ | 0.9 | 0.2 | 0.2 | 0.2 | 0.9 |
| $v_n(x)$ | 0.1 | 0.7 | 0.7 | 0.7 | 0.0 |

we have

$$d_3(J,K) = \frac{1}{n}\sum_{i=1}^{n} \frac{|\mu_J(s_i) - \mu_K(s_i)| + |\nu_J(s_i) - \nu_K(s_i)|}{4} + \frac{max(|\mu_J(s_i) - \mu_K(s_i)|, |\nu_J(s_i) - \nu_K(s_i)|)}{2} \quad (40)$$

since from the Table 4 and using $d_2(P,Q)$ we get following result

$d_3(c_1,n) = 0.305, d_3(c_2,n) = 0.285, d_3(c_3,n) = 0.460, d_3(c_4,n) = 0.315$

which implies special metal n is produced from metal field $c_2$.

**Definition 22.** *[28] The variance margin function (V-MF) of T2IFS is defined as the difference between P-MF and S-MF, P-NMF and S-NMF. It is denoted by $\eta$ and $\xi$ respectively.*

Now we extended this new distance measure for T2IFSs and provided the comparison between this distance measure with exixting distance measure with a numerical example.

# 4. New Distance measures between T2IFS

Firstly we analyse the definition of "distance measure for T2IFS". Singh, S., & Garg, H. [28] defined the concept for T2IFS where they used triangle inequality and we defined the inclusion relation between T2IFS which is not satisfied by euclidean distance measure It is necessary to establish the inclusion relation between T2IFS, so we introduced a new distance measure which satisfies inclusion relation in T2IFS.

For convenience, two T2IFSs $P$ and $Q$ in T are denoted by $P = \{t(u, f_{tj}(u_P), (v, g_{tj}(v_P))|t \in T\}$ and $Q = \{t(u, f_{tj}(u_Q), (v, g_{tj}(v_Q))|t \in T\}$ then we defined new distance for $P$ and $Q$ by considering the P-MF,S-MF,P-NMF and S-NMF

$$d_4(P,Q) = \frac{1}{2n}\sum_{i=1}^{n}\frac{|u_P(t_i)-u_Q(t_i)|+|v_P(t_i)-v_Q(t_i)|+|f_{ti}(u_P)-f_{ti}(u_Q)|+|g_{ti}(u_P)-g_{ti}(u_Q)|}{4} + \frac{max|u_P(t_i)-u_Q(t_i)|,|v_P(t_i)-v_Q(t_i)|,|f_{ti}(u_P)-f_{ti}(u_Q)|,|g_{ti}(u_P)-g_{ti}(u_Q)|}{2} \tag{41}$$

**Definition 23.** *A real function $d_4\colon F_2^I(t)\times F_2^I(t)\rightarrow[0,1]$ is called distance measure, where $d_4$ satisfies the following axioms:*

$$(p1)\quad 0\leq d_4(P,Q)\leq 1,\ \forall\ (P,Q)\in F_2^I(t) \tag{42}$$

$$(p2)\quad d_4(P,Q)=0,\ IF\quad P=Q \tag{43}$$

$$(p3)\quad d_4(P,Q)=d_4(Q,P) \tag{44}$$

$$(p4)\quad P\subseteq Q\subseteq R\ \ where\ \ P,Q,R\in F_2^I(t),\ \ then\ \ d_4(P,R)\geq d_4(P,Q)\ \ and\ \ d_4(P,R)\geq d_4(Q,R). \tag{45}$$

Now we will prove the above defined measure is a valid distance measure for T2IFS. condition $(P_1)$given in eq 27

$$(P_1)\implies 0\leq d_4(P,Q)\leq 1$$

Let P and Q be two T2IFS then we have
$|u_P(t_i)-u_Q(t_i)|\geq 0, |f_{ti}(u_P)-f_{ti}(u_Q)|\geq 0$

$|v_P(t_i)-v_Q(t_i)|\geq 0, |g_{ti}(u_P)-g_{ti}(u_Q)|\geq 0$
this implies $d_2(P,Q)\geq 0$
then we have $|u_P(t_i)-u_Q(t_i)|\leq 1, |f_{ti}(u_P)-f_{ti}(u_Q)|\leq 1$

$|v_P(t_i)-v_Q(t_i)|\leq 1, |g_{ti}(u_P)-g_{ti}(u_Q)|\leq 1$
$\implies d_4(P,Q)\leq 1$ hence

$$0\leq d_4(P,Q)\leq 1$$

condition $(P_2)$ given by eq 28 follows trivialy so we prove for $(P_3)$ and $(P_4)$ condition given in eq 29 and 30 respectively.

$$(P_3)\implies d_4(P,Q)=d_4(Q,P)$$

we have

$$d_4(P,Q) = \frac{1}{2n}\sum_{i=1}^{n}\frac{|u_P(t_i)-u_Q(t_i)|+|v_P(t_i)-v_Q(t_i)|+|f_{ti}(u_P)-f_{ti}(u_Q)|+|g_{ti}(u_P)-g_{ti}(u_Q)|}{4} + \frac{max|u_P(t_i)-u_Q(t_i)|,|v_P(t_i)-v_Q(t_i)|,|f_{ti}(u_P)-f_{ti}(u_Q)|,|g_{ti}(u_P)-g_{ti}(u_Q)|}{2} \tag{46}$$

$$= \frac{1}{2n}\sum_{i=1}^{n}\frac{|u_Q(t_i)-u_P(t_i)|+|v_Q(t_i)-v_P(t_i)|+|f_{ti}(u_Q)-f_{ti}(u_P)|+|g_{ti}(u_Q)-g_{ti}(u_P)|}{4} + \frac{max|u_Q(t_i)-u_P(t_i)|,|v_Q(t_i)-v_P(t_i)|,|f_{ti}(u_Q)-f_{ti}(u_P)|,|g_{ti}(u_Q)-g_{ti}(u_P)|}{2} \tag{47}$$

$$= d_4(Q,P)$$

$$\implies d_4(P,Q) = d_4(Q,P)$$

Now to prove $(P_4)$

$$(P_4) \implies d_4(P,R) \geq d_4(P,Q) \tag{48}$$

it is easy to see that $|u_P(t_i)-u_R(t_i)| \geq |u_P(t_i)-u_Q(t_i)|, |f_{ti}(u_P)-f_{ti}(u_R)| \geq |f_{ti}(u_P)-f_{ti}(u_Q)|$ $|v_P(t_i)-v_R(t_i)| \geq |v_P(t_i)-v_Q(t_i)|, |g_{ti}(u_P)-g_{ti}(u_R)| \geq |g_{ti}(u_P)-g_{ti}(u_Q)|$ so we have

$$\frac{1}{2n}\sum_{i=1}^{n}\frac{|u_P(t_i)-u_R(t_i)|+|v_P(t_i)-v_R(t_i)|+|f_{ti}(u_P)-f_{ti}(u_R)|+|g_{ti}(u_P)-g_{ti}(u_R)|}{4} + \frac{max|u_P(t_i)-u_R(t_i)|,|v_P(t_i)-v_R(t_i)|,|f_{ti}(u_P)-f_{ti}(u_R)|,|g_{ti}(u_P)-g_{ti}(u_R)|}{2} \tag{49}$$

$$\geq \frac{1}{2n}\sum_{i=1}^{n}\frac{|u_P(t_i)-u_Q(t_i)|+|v_P(t_i)-v_Q(t_i)|+|f_{ti}(u_P)-f_{ti}(u_Q)|+|g_{ti}(u_P)-g_{ti}(u_Q)|}{4} + \frac{max|u_P(t_i)-u_Q(t_i)|,|v_P(t_i)-v_Q(t_i)|,|f_{ti}(u_P)-f_{ti}(u_Q)|,|g_{ti}(u_P)-g_{ti}(u_Q)|}{2} \tag{50}$$

then we get inequality $d_4(P,R) \geq d_4(P,Q)$ similarly we can prove $d_4(P,R) \geq d_4(Q,R)$ hence satisfies condition $(P_4)$ so we proved this is a valid distance measure for T2IFS

## 4.1. Numerical Example

Lets consider four kinds of metal fields and each field is featured by five metals . We can express these four fields by T2IFSs $\{c_1, c_2, c_3, c_4\}$ in space $\{T = t_1, t_2, t_3, t_4, t_5\}$.See Table 6. There is another kind of special metal $\{n\}$ so we have to find which metal field this metal belongs.

Table 6

| | $t_1$ | $t_2$ | $t_3$ | $t_4$ | $t_5$ |
|---|---|---|---|---|---|
| $u_{c_1}(t)$ | 1 | 0.7 | 0.5 | 0.7 | 1 |
| $f_t(u_{c_1})$ | 0.7 | 0.9 | 0.2 | 0.5 | 0.9 |
| $v_{c_1}(t)$ | 0 | 0.1 | 0.4 | 0.2 | 0 |
| $g_t(u_{c_1})$ | 0.2 | 0.1 | 0.5 | 0.4 | 0.1 |
| $u_{c_2}(t)$ | 1.0 | 0.7 | 0.9 | 0.9 | 0.9 |
| $f_t(u_{c_2})$ | 0.9 | 0.7 | 1.0 | 0.7 | 0.7 |
| $v_{c_2}(t)$ | 0 | 0.4 | 0.1 | 0.1 | 0.1 |
| $g_t(u_{c_2})$ | 0.1 | 0.4 | 0 | 0.2 | 0.2 |
| $u_{c_3}(t)$ | 1.0 | 0.9 | 1.0 | 0.9 | 0.9 |
| $f_t(u_{c_3})$ | 0.7 | 1.0 | 0.9 | 0.9 | 0.4 |
| $v_{c_3}(t)$ | 0.0 | 0.1 | 0.0 | 0.1 | 0.1 |
| $g_t(u_{c_3})$ | 0.2 | 0 | 0.1 | 0.1 | 0.5 |
| $u_{c_4}(t)$ | 0.9 | 0.9 | 0.9 | 0.2 | 0.7 |
| $f_t(u_{c_4})$ | 1.0 | 0.7 | 0.5 | 0.0 | 0.4 |
| $v_{c_4}(t)$ | 0.1 | 0.0 | 0.1 | 0.7 | 0.2 |
| $g_t(u_{c_4})$ | 0 | 0.1 | 0.4 | 1.0 | 0.5 |
| $u_n(t)$ | 0.9 | 0.2 | 0.2 | 0.2 | 0.9 |
| $f_t(u_n)$ | 0.4 | 0.5 | 0.4 | 0.0 | 0.7 |
| $v_n(t)$ | 0.1 | 0.7 | 0.7 | 0.7 | 0.0 |
| $g_t(u_n)$ | 0.5 | 0.4 | 0.5 | 1.0 | 0.1 |

we have

$$d_4(P,Q) = \frac{1}{2n}\sum_{i=1}^{n}\frac{|u_P(t_i)-u_Q(t_i)|+|v_P(t_i)-v_Q(t_i)|+|f_{ti}(u_P)-f_{ti}(u_Q)|+|g_{ti}(u_P)-g_{ti}(u_Q)|}{4} + \frac{max|u_P(t_i)-u_Q(t_i)|,|v_P(t_i)-v_Q(t_i)|,|f_{ti}(u_P)-f_{ti}(u_Q)|,|g_{ti}(u_P)-g_{ti}(u_Q)|}{2} \tag{51}$$

since from the Table 4 and using $d_2(P,Q)$ we get following result

$d_2(c_1,n) = 0.275, d_2(c_2,n) = 0.312, d_2(c_3,n) = 0.385, d_2(c_4,n) = 0.259$

which implies special metal n is produced from metal field $c_4$ obviously this coincides with the result of Sukhveer Singh and Harish Garg [28] but there approach is not valid for some calculations as it gives value beyond 1.0 which means our approach is better and also our approach includes inclusion relation which is stronger than triangle inequality.

## Analysis on the basis of distance measure for different fuzzy sets

Type-1 fuzzy sets (T1FSs) are distinguished by membership functions that are created using the degree of membership between each element, set in the range [0, 1]. Yet, a wide variety of recent publications on decision-making issues have taken intuitionistic fuzzy sets (IFSs) into account to handle the ambiguity. IFSs are the generalised version of fuzzy sets proposed by Atanassov [2], which gives the freedom to also model the reluctance in the decision-making). They are specified by a membership and a non-membership degree, and the hesitation margin is obtained by subtracting both from unity. Yet, as these traditional T1FSs or IFSs still have crisp membership values, they are frequently linked to interpretability problems. There is a membership and a non-membership in type-1 when dealing with these classical intuitionistic fuzzy sets, and it is thought that the uncertainty in the evaluation can be seen of as dissipating. There may still be some confusion close to the membership and non-membership boundaries, though. Moreover, confusing and imprecise information tends to be more prevalent in real-world application contexts. Type-2 membership function can be used to solve this issue, as type-2 fuzzy sets demonstrate (T2FSs). It can be easily seen from the above defined two examples for T1IFS and T2IFS respectively. In first example we use only membership and non-membership values but in 2nd example we take secondary membership and secondary non-membership values into consideration, so it better to use T2IFS instead of T1IFS when the uncertainty is so high. We analysed different fuzzy sets and calculated the distance measures between these sets by using numerical examples to check out the comparison and we found that T2IFS are better.

### Results of Comparison

To understand their importance, a comparison based on distance measures was conducted, using examples for each type of fuzzy set. Distance measures provide a quantitative assessment of similarity or dissimilarity between fuzzy sets. Through these examples, it becomes apparent that T2IFSs outperform the other fuzzy sets when faced with ambiguous or uncertain information.

## 5. Conclusion

Operation of union and intersection between T1FS,T2FS,IFS and T2IFS is discussed with the help of examples, to understand the importance of these fuzzy sets a comparison is made on the basis of distance measures by the aid of examples on each above defined fuzzy sets. However, it is worth noting that the existing distance measures for T2IFSs have limitations. To address this, a new distance measure is proposed specifically tailored for T2IFSs. This measure overcomes the limitations of the existing one, enabling a more accurate and reliable comparison of T2IFSs. In conclusion, when faced with decision-making scenarios where information is ambiguous or uncertain, it is better to utilize T2IFSs. Their ability to consider both membership and non-membership values, along with the proposed improved distance measure, allows for a more comprehensive and effective analysis of fuzzy information. By employing T2IFSs in such conditions, decision-makers can obtain more reliable and informed outcomes, leading to better decision-making overall.

## Conflict of interest

The authors declares no conflict of interest.

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# Exploring the potential of peach (Prunus Persica L.) nut-shells as a sustainable alternative to traditional aggregates in lightweight concrete

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## Abstract

This study investigates the potential application of peach shells as lightweight aggregates in the production of non-structural lightweight concrete (LWC). The recycling and reutilization of agri-food waste presents an opportunity to address the challenges associated with waste disposal and limit the exploitation of natural resources, contributing to sustainable development goals and combatting climate change. The peach shells were subjected to heat treatment at various temperatures (160, 200, and 240 °C) to reduce the hydrophilicity of the cellulose fraction, and their chemical and physical properties were examined in relation to the performance of lightweight concrete, in terms of density, compressive strength and thermal conductivity. Two binding mixtures, one with lime only (mixture "a") and the other with both lime and cement (mixture "b"), were studied. The experimental results indicated that the prepared lightweight concrete specimens exhibited better performance as the roasting temperature increased, starting from 200 °C. Conversely, specimens prepared with peach shells roasted at 160 °C exhibited a decreased performance compared to those prepared with only air-dried peach shells. Samples prepared with the mixture "a" have better insulating properties and lower density, but lower mechanical resistance. The enhanced properties observed in the lightweight concrete specimens prepared with higher roasting temperatures highlight the potential of utilizing peach shells as an effective and sustainable alternative to traditional lightweight aggregates.

**Keywords: sustainability; green building; recycle; food waste; lightweight concrete; lime concrete; fruit shells; coarse aggregate replacement**

## 1. Introduction

The impact of the construction industry on the environment is an important issue that needs to be addressed to achieve sustainable development [1,2]. The construction sector is a significant contributor of environmental pollution. Currently, it is responsible for consuming approximately 32% of natural resources and producing approximately 25% of the solid waste generated worldwide [3–5]. In addition, it is a primary source of carbon emissions [6]. Construction industry activities are linked not only to environmental issues but also to socioeconomic and cultural aspects [7–9]. It plays a vital role in any economy by providing employment opportunities, boosting gross domestic product (GDP), and creating strong infrastructure that drives progress [9,10]. The rapid increase in global population has led to a growing demand for urbanization [11], emphasizing the need to identify low-cost building materials that can meet this growing demand while remaining accessible and affordable [9]. Currently, approximately three billion people live in slum conditions because of slow urbanization, which is exacerbated by continued global population growth. The construction sector accounts for approximately 50% of global energy consumption [9,12,13], highlighting the pressing need to develop eco-friendly building materials. With the rising demand for urbanization, buildings must be energy-efficient to meet ever-increasing energy requirements [14,15]. Advanced and effective insulation materials, for example, can help reduce the environmental impact of buildings by increasing their efficiency and reducing their energy consumption [15]. By adopting sustainable building practices, the construction industry can provide safe and affordable housing for city dwellers, promote economic growth, create job opportunities, and improve the overall wellbeing of individuals and communities. The adoption of green building methods can contribute to Sustainable Development Goals by addressing global challenges [8].

An effective way to reduce the consumption of natural resources and mitigate environmental problems related to raw material extraction is to use industrial waste from the construction industry itself or from other productive sectors such as the agro-industrial sector. Agri-food waste is often regarded as an environmental issue; however, recent developments have revealed its potential for use as a sustainable solution in the construction industry [16–20]. In particular, agri-food waste can be used as lightweight aggregate in the production of lightweight concrete (LWC) [21,22]. LWC is a versatile building material that offers numerous advantages over traditional concrete [23–25]. As the name suggests, this type of concrete is significantly lighter than traditional concrete and requires fewer materials to achieve the same level of structural integrity, thereby reducing the overall weight of the structure. Furthermore, LWC exhibits better thermal insulation properties than traditional concrete owing to its lower density, which reduces the amount of energy required for heating and cooling, resulting in lower energy consumption and environmental impact [26]. The thermal conductivity is typically lower than 1 W/m°C and the dry density is up to 2000 kg/m3. Therefore, LWC is used when low weight and insulating properties are relevant. In addition, LWC provides improved acoustic insulation, reduces noise pollution, and provides a quieter and more comfortable living environment. The use of bio-based lightweight aggregates represents a feasible approach for achieving more sustainable construction. When agri-food waste is used as an aggregate, it not only uses up what would otherwise be landfill waste but also reduces the need for natural aggregates, which are often heavy, energy-intensive, and have a significant carbon footprint as they require significant transport to the building site. Moreover, the use of agri-food waste as an aggregate in lightweight concrete directly benefits the local communities. The community would benefit from the economic value of these low-value resources, as using them for construction would generate employment opportunities, particularly in rural areas and small towns where agricultural and food waste is abundant.

This study focused on exploring the potential of Rosaceae nutshells as an eco-friendly alternative to traditional aggregates in LWC. In particular, the potential of peach (Prunus persica L.) shells as lightweight aggregates was assessed. Peaches are widely cultivated [27], and their shells are considered low-value agro-industrial residues [28]. According to the "Food and Agriculture Organization (FAO)", global peach production was approximately 24 million tons in 2020. The pulp of Rosaceae fruits is highly valued by agro-industries because of its versatility in making juices, canned fruits, jams, and sweet snacks. All these productive sectors generate a significant amount of waste pits, which make up approximately 10% of the total mass produced [29]. Currently, the main alternative to landfilling fruit shells is the incineration of biomass heating systems. However, this activity requires temporary storage of the shells in large piles outdoors, with consequent problems such as space availability, environmental hygiene issues, and the development of odorous fumes due to uncontrolled fermentation of the pulp residues and decomposition of the organic material [30]. The second and more important factor is the serious environmental effects caused by the incineration of these materials. The combustion of agricultural residues such as wood, leaves, trees, and grass generates approximately 40% of CO2 emissions, 20% of fine particles, and 50% of polycyclic aromatic hydrocarbons (HAPs) [31]. The use of peach shells as aggregates for sustainable building is linked to some of their characteristics, which make them very interesting. First, their degradation under natural conditions is difficult and slow, unlike that of other food waste by-products [32,33]. Furthermore, they have considerable porosity, which results in a considerable reduction in the thermal conductivity [34]. Finally, being a widely available and low-cost waste material, its reuse and valorization are perfectly in line with the 2030 Agenda for Sustainable Development [35]. However, the main concern is the high water absorption of the cement mix by the biomass aggregates. Increased water absorption leads to swelling, cracking, and the subsequent loss of durability and mechanical strength [36–38]. This phenomenon can be reduced by the heat treatment of materials using a roasting procedure [34]. In this study, peach shells were roasted at 160, 200, and 240 °C to evaluate the effect of aggregate pretreatment on the performance of LWC. Heat treatment imparts an increase in dimensional stability to the fruit shells owing to lower water absorption. This phenomenon is due to the degradation of the hydroxyl groups of the cellulosic fraction, which results in a decrease in the water absorption capacity of the biomass [39,40]. Therefore, heat treatment of peach shells can be an effective method for improving the performance of peach shell concrete (PSC).

In this study, two lime-based cement mixtures are investigated. This binding material has been used in civil engineering [37,41,42], and only a few studies have evaluated its potential as an alternative to Portland cement [43,44]. Lime offers several environmental advantages compared to cement-based materials. Its raw material, limestone, is burned at lower temperatures than cement; therefore, lime requires less energy. Furthermore, part of the CO2 generated during its production is reabsorbed by hardened lime [45]. In addition, lime-based concrete is more porous, resulting in a decrease in density and thermal conductivity. Therefore, it is an eco-friendly material compared to concrete, even though it leads to materials that are much less mechanically resistant.

This study presents a novel approach for sustainable lightweight concrete production by exploring the potential utilization of peach shells as coarse aggregates. To the best of our knowledge, this is the first comprehensive investigation of the incorporation of roasted peach shells into lime-based concrete mixtures to enhance sustainability and reduce environmental impact. We aim to contribute to the development of innovative and eco-friendly construction materials by harnessing the inherent properties of peach shells and their abundance as agricultural waste. By systematically evaluating the physical, mechanical, and durability properties of peach-shell-based lightweight concrete, we aim to provide valuable insights into its feasibility and performance.

## 2. Methodology

### *2.1. Raw materials properties and Specimens preparation*

#### 2.1.1. Binder Mixture

The main binder used was hydrated lime (Litokol S.p.A., 42048 Rubiera, Italy). To improve the mechanical properties, a few sets of specimens were prepared with the addition of Typica I 52.5 grade Portland cement (Litokol S.p.A., 42048 Rubiera, Italy). The physical and chemical properties of the binders are listed in Table 1.

Table 1

Physical and chemical properties of the binders

| | Hydrated lime | Cement 52.5 |
|---|---|---|
| **Chemical analysis (wt%)** | | |
| *$SiO_2$* | - | *19.8* |
| *CaO* | *75.68* | *63.89* |
| *$Al_2O_3$* | - | *4.43* |
| *$Fe_2O_3$* | - | *3.08* |
| *$SO_3$* | - | *3.77* |
| *MgO* | - | *1.02* |
| *$Na_2O$* | - | *0.09* |
| *$K_2O$* | - | *0.67* |
| *$TiO_2$* | - | *0.18* |
| **Physical Properties** | | |
| *Bulk density ($kg/m^3$)* | *450* | *770* |
| *Specific gravity ($g/cm^3$)* | *2.24* | *2.75* |
| *Compressive strength 7 days ($N/mm^2$)* | - | *30* |
| *Compressive strength 28 days ($N/mm^2$)* | - | *52.5* |

### 2.1.2. Coarse and fine aggregates

Crushed shells were used as alternative coarse aggregates (Fig. 1). The peaches were sourced from a local orchard in Modena, Italy, and bought from a nearby supermarket. The pulp was separated from the pits, cleaned before use, and the residual dried pulp and dust on their surfaces were removed. The pits were preliminarily air-dried for 30 days, to remove residual moisture, after which the external shell was separated from the internal kernel through coarse grinding. A crushing machine was used to crush the dried shells, and they were then sieved with 4.5 and 9.5 mm sieves. Three sets of roasted peach shells were prepared by placing them in glass container and heated in an inert atmosphere ($N_2$) for two hours at 160, 200, 240 °C, respectively (PS160, PS200 and PS240, respectively). One set was kept simply air dried (PS). Natural alluvial silica sand was used as the fine aggregate (Litokol S.p.A., 42048 Rubiera, Italy). The physical properties of the aggregates are listed in Table 2, and the proximate chemical compositions of the fruit shells are listed in Table 3.

Table 2

Physical properties of coarse and fine aggregates

| | Coarse aggregate | | | | Fine aggregate |
|---|---|---|---|---|---|
| **Physical property** | **PS** | **PS160** | **PS200** | **PS240** | **Sand** |
| *Particle size (mm)* | *4.5 – 9.5* | *4.5 – 9.5* | *4.5 – 9.5* | *4.5 – 9.5* | *1* |
| *Specific gravity (kg/dm$^3$)* | *1.28$^a$* | *1.24 ± 0.05* | *1.21$^a$* | *1.19$^a$* | *1.5* |
| *Bulk density (kg/m$^3$)* | *556 ± 2* | *528 ± 1* | *520 ± 2* | *514 ± 3* | *1560* |
| *Water absorption (24h) (%)* | *15.2 ± 0.3* | *16.1 ± 0.5* | *8.7 ± 0.3* | *7.8 ± 0.2* | *1.1* |
| *Shape* | *Flaky* | *Flaky* | *Flaky* | *Flaky* | *Tout-venant* |

PS = Peach Shells, $^a$SD<0.05

Table 3

Proximal chemical composition of Peach shells

| | **PS** | **PS160** | **PS200** | **PS240** |
|---|---|---|---|---|
| *Moisture (%)** | *4.2 ± 0.7* | - | - | - |
| *Mass loss (%)* | - | *5.1 ± 0.6* | *5.5 ± 0.3* | *6.4 ± 0.5* |
| *Ash (%)* | *1.0 ± 0.2* | *1.8 ± 0.3* | *2.3 ± 0.1* | *3.0 ± 0.2* |
| *C (%)* | *47.7 ± 0.5* | *48.3 ± 0.9* | *50.9 ± 0.7* | *59.0 ± 0.7* |
| *H (%)* | *5.7 ± 0.1* | *5.5 ± 0.2* | *5.6 ± 0.1* | *5.2 ± 0.3* |
| *N (%)* | *0.2$^a$* | *0.3$^a$* | *0.3$^a$* | *0.3$^a$* |
| *O (%) (from difference)* | *45.4 ± 0.8* | *44.1 ± 0.11* | *40.9 ± 0.9* | *32.5 ± 0.12* |
| *Protein content (%)* | *1.2$^a$* | *1.9$^a$* | *1.9$^a$* | *1.9$^a$* |
| *Fat (%)* | *0.1$^a$* | *0.1$^a$* | *0.1$^a$* | *0.1$^a$* |

PS = Peach Shells, $^a$SD<0.05
*On dry basis

The methods recommended by the Association of Official Analytical Chemists were used to determine the levels of moisture, ash, crude protein, and residual oil. Moisture content was determined by drying the samples at 105 °C to a constant weight. The ash content was determined using a laboratory furnace at 550 °C and the temperature was gradually increased. Nitrogen content was determined using the Dumas method and converted to protein content by multiplying by a factor of 6.25. The residual fat fraction was recovered using the Soxhlet method, exhaustively extracting 10 g of each sample using petroleum ether (boiling point range 40 – 60 °C) as the extractant solvent. Each measurement was performed at least in triplicate, and the results were averaged.

It is important to note that various factors have a significant impact on the chemical composition and physical properties of vegetable matrices, such as geographical origin, level of ripeness, and specific cultivar they originate from [46].

Figure 1 shows the values of mass loss (Δm%) and specific gravity (kg/dm$^3$) against roasting temperature.

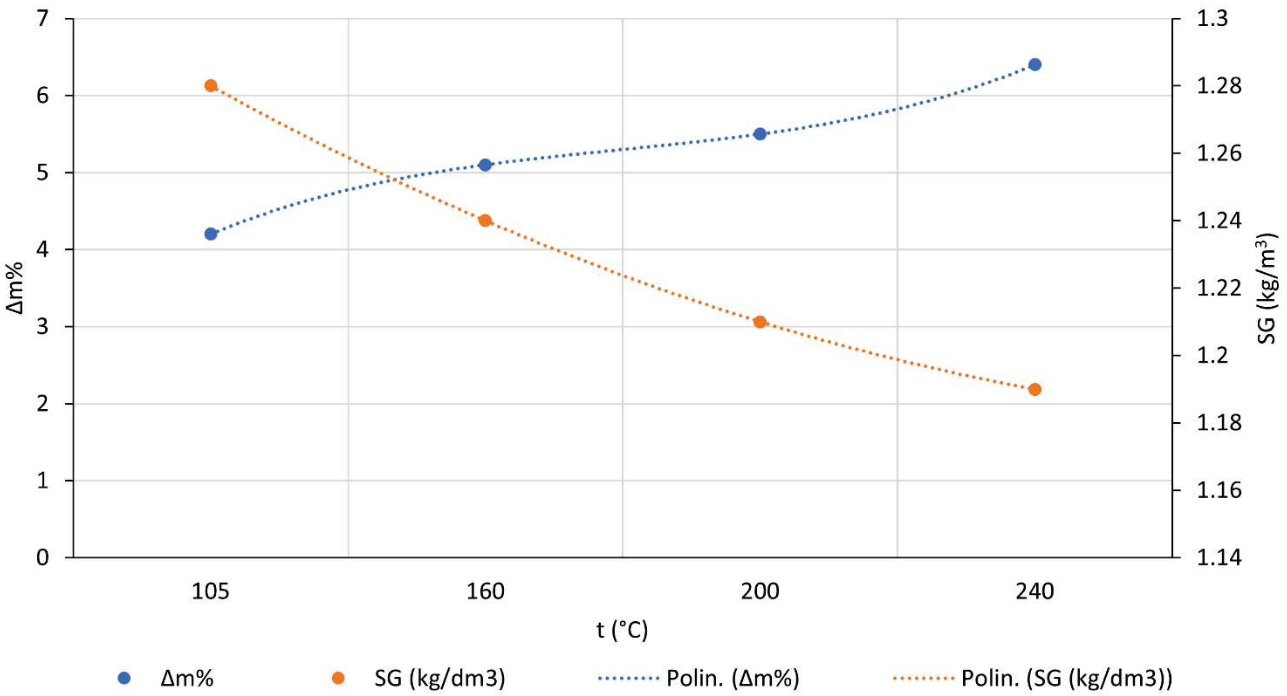


*Fig. 1. Mass loss (Δm%) and specific gravity (kg/dm$^3$) values against the roasting temperature (°C) of peach shells.*

The trend of $\Delta m$ $vs$ $t$ $(°C)$ is commonly observed in wood roasting processes, although it varies numerically depending on the matrix being studied.

In Table 3, the $\Delta m$ and specific gravity ($SG$) values are correlated with the roasting temperature ($°C$) using a polynomial best-fit operation. The resulting equations (Eq. 1 and 2) facilitate the interpolation of mass loss for any temperature of interest within the range 105-240 °C, enabling a comparison of the effects induced on the other variables that can be useful for any applications.

$$\Delta m\%: y = 0.1667x3 - 1.2500x2 + 3.4833x + 1.8 \tag{1}$$

$$SG: y = -3E - 14x3 + 0.005x2 - 0.055x + 1.33 \tag{2}$$

### 2.1.3. Lime-concrete design and specimen preparation

Normal tap water was used in this study. The mix proportions of all specimens are listed in Table 4. For each shell, the mix proportion of the related concrete was kept constant (PS = LWC with dried Peach Shell; PS160 = LWC with Peach Shell roasted at 160 °C; PS200 = LWC with Peach Shell roasted at 200 °C; PS240 = LWC with Peach Shell roasted at 240 °C). Specimens were removed from the mold after 24 hours. They were stored in a laboratory room with a relative humidity of 95 ± 5 % and a temperature of 20 ± 2 °C until the test age. Binder mixture "a" only includes lime, while mixture "b" involved the addition of cement. Three sets of specimens were prepared: one for the compressive strength test, one for the demolded, air-dry, and oven-dry density evaluation, and one for the thermal conductivity test. Each set contained three cubic specimens (100 × 100 × 100 mm3), and the average values were obtained for each test result.

The specimens were prepared as follows: river sand, lime, and cement were poured into a blender and dry-mixed for 1 min. Water was added and the mixture was mixed for 3 min. The lightweight aggregates were finally added to and mixed for 5 min. After mixing, fresh mixtures were then poured into the mold and compacted. The specimens were placed in the laboratory room and were removed from the molds after approximately 24 h.

Table 4

Mix proportion of LWC samples

| Sample | Lime* | Cement* | Sand* | Lightweight aggregate* | w/b ratio# |
|---|---|---|---|---|---|
| ***PS_a*** | *585* | - | *625* | *350* | *0.45* |
| ***PS160_a*** | *585* | - | *625* | *339* | *0.45* |
| ***PS200_a*** | *585* | - | *625* | *330* | *0.45* |
| ***PS240_a*** | *585* | - | *625* | *325* | *0.45* |
| ***PS_b*** | *390* | *195* | *625* | *350* | *0.4* |
| ***PS160_b*** | *390* | *195* | *625* | *339* | *0.4* |
| ***PS200_b*** | *390* | *195* | *625* | *330* | *0.4* |
| ***PS240_b*** | *390* | *195* | *625* | *325* | *0.4* |

PS = Peach Shells

*kg/$m^2$

#water-binder ratio


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## 2.2. *Experimental methods*

### 2.2.1. Morphological analysis of the aggregates

The field emission scanning electron microscope (SEM) instrument (Nova Nano-SEM 450, 20 kV) was used to evaluate the microscopic morphology of coarse light-weight aggregates.

### 2.2.2. Demolded, Air-dry and Oven-dry densities

Demolded, air-dry and oven-dry densities were determined following ASTM C567. The demolded mass was measured after demolding (after 24h of curing), and the air-dry mass was measured after 28-day of curing. The test method for oven-dry density is more complex. The specimens were immersed in water (at about 20 °C) for 48 h, then the surface water was removed with filter paper, and the saturated surface-dry mass was measured. Then, it was suspended in water with a wire, and the apparent mass of the suspended-immersed specimens was determined. The samples were then oven-dried at 110 °C for 72 h. The oven-dry density was calculated from Eq. (3):

$$O\_m = \frac{D \times 997}{F - G} \tag{3}$$

where $Om$ is the measured oven-dry density (kg/m3); $D$ is the specimen mass (kg); $F$ is the mass of saturated surface-dry specimen (kg); $G$ is the apparent mass of suspended-immersed specimen (kg).

### 2.2.3. Mechanical test

The compressive strength test was performed after 28- and 56-day using a Technotest compression test machine (Technotest, Modena, Italy). The average value of at least three specimens was used as the test result. It was performed in conformity with the European standard for structural concrete (EN 12390-3:2009), although our concrete had no structural purpose. Lime mortar (EN 1015-11:1999) would be more suitable for the intended use, but the presence of coarse aggregates prevents its application.

### 2.2.4. Thermal Conductivity of Lime-concrete specimens

A KD2 Pro thermal properties analyser (Decagon Inc., Pullman WA 99163, USA) was used for thermal conductivity measurements. It is a portable device fully compliant with ASTM D5334-08 and is used to measure the thermal properties of materials based on probe/sensor methods (transient line heat source), as confirmed by Decagon Devices Inc. Operator Manual version 11. It consists of a portable controller and sensors probe to be inserted into the medium to be measured. The measurement consists of heating the probe for a certain time and monitoring the temperature during heating and cooling. The influence of the ambient temperature on the samples must be minimized to obtain more accurate values. The measurement range of thermal conductivity of KD2 Pro is 0.02 to 2.00 W/(mK). In this study, three cubic specimens for each sample (100 × 100 × 100 mm3), at 28 days of curing were selected to measure thermal conductivity at dry conditions. The samples were oven-dried for 24 hours at 100 °C prior to testing.

## 3. Results and Discussion

### 3.1. Lightweight aggregates

The peach shell samples naturally dried and roasted at 160, 200 and 240 °C are shown in Figure 2.

As previously mentioned, we obtained peach pits independently by purchasing ripe fruits from the supermarket and separating the wood fraction. However, for industrial supplies and applications, there are several dealers in the region who sell chopped fruit shells, which are currently used as biomass fuel [47].

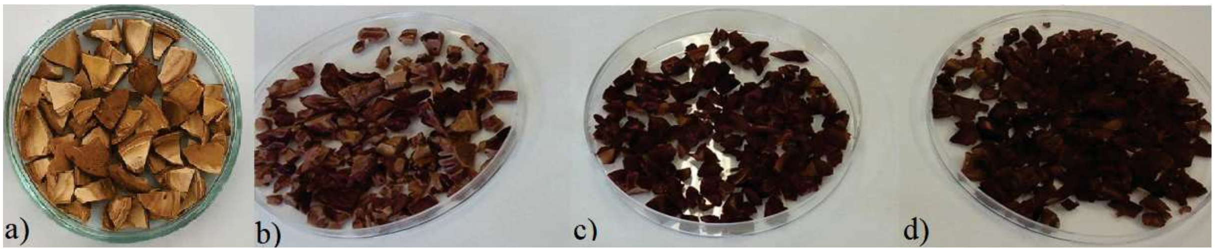

*Fig. 2. Peach shell samples: naturally dried (a), roasted at 160 °C (b), 200 °C (c), 240 °C (d)*

The physical and mechanical properties of LWC are strongly influenced by the nature, composition, and physical properties of the lightweight aggregates used [36,48,49]. The specific characteristics of the aggregate have a significant impact on the type of application and use of the final product [50]. Therefore, a thorough understanding of the properties and characteristics of peach shells is essential for their potential use as lightweight aggregates. Additionally, it is important to examine how the chemical and physical properties of the peach shells are affected by variations in the roasting temperature to establish a correlation between the pre-treatment process and the performance of the LWC.

Table 2 presents the physical properties of the peach shell samples, including particle size, specific gravity, bulk density, water absorption, and shape. The results clearly show how different roasting temperatures can affect the physical properties of peach shells. The specific gravity decreased as the roasting temperature increased, with PS having the highest value of 1.28 and PS240 having the lowest value of 1.19. Similarly, the bulk density decreased as the roasting temperature increased, with PS exhibiting the highest value of 556 kg/m3 and PS240 exhibiting the lowest value of 514 kg/m3. The bulk density of lightweight aggregates plays a critical role in determining the mechanical and insulation properties of LWC [37]. This feature is closely related to the size, shape, moisture content, and porosity of the aggregates. The strong decrease in specific gravity and bulk density is mainly related to the strong loss of moisture and volatile organic compounds (VOCs) that occurs following heat treatment. The water absorption initially increased from the PS sample to PS160, while it drastically decreased at the following temperatures, reaching a minimum at PS240. This observation proves the reduction in the hydroxyl functional groups of the cellulosic fraction, which are responsible for the interaction of the woody matrix with water molecules [51]. It is likely that the temperature of 160 °C was not high enough to trigger these degradation processes, resulting in a strong dehydration effect on the material without any reduction in its water absorption capacity. This observation is not completely unexpected, as it is known that H2O loss following the thermal treatment of lignocellulosic matrices becomes significant after 200 °C [52,53]. The water absorption characteristics of lightweight aggregates are typically and significantly greater than those of traditional coarse aggregates, primarily because of their higher porosity, and different chemical composition. In particular, fruit shells are composed primarily of three key natural polymers – cellulose, lignin, and hemicellulose – which are typical components of lignocellulosic biomass [52,54,55]. Compared to lignin, which acts as an adhesive between cellulose and hemicellulose and is highly hydrophobic [56,57], cellulose has a distinct ability to absorb water. Therefore, it is essential to develop approaches that can reduce the water affinity of the cellulose fraction and, consequently, limit the water absorption of lightweight aggregates. In fact, water absorption can negatively impact important properties of LWC, such as density, strength, durability, and time-dependent deformation [36,37].

Table 3 highlights the proximal chemical composition of the peach shell samples, including the samples roasted at different temperatures. It provides a general overview of the differences in the chemical constituents, demonstrating the impact of roasting on organic material and elemental composition. As expected, the mass loss increased as the roasting temperature increased, with PS240 exhibiting the highest mass loss. Similarly, the ash content increased with higher roasting temperatures due to the partial removal of organic content. The carbon content progressively increased with increasing roasting temperature, whereas the oxygen content decreased, indicating the removal of oxygen-containing functional groups. This clearly explains the decrease in water absorption with increasing roasting temperature.

## 3.2. Morphological analysis of Peach Shells

The surfaces of peach shells (PS) are shown in Fig. 3a, 3b, and 3c. We reported only the images related to naturally dried PS because we did not identify significant differences between the roasted samples. Furthermore, we only presented images relating to the outer surface, which allowed the evaluation of material porosity. In fact, the internal surface was extremely smooth and compact; therefore, it seemed more important to focus only on the outer surface, as it probably contributed more to the properties of the aggregates and, consequently, to the behavior of the specimens.

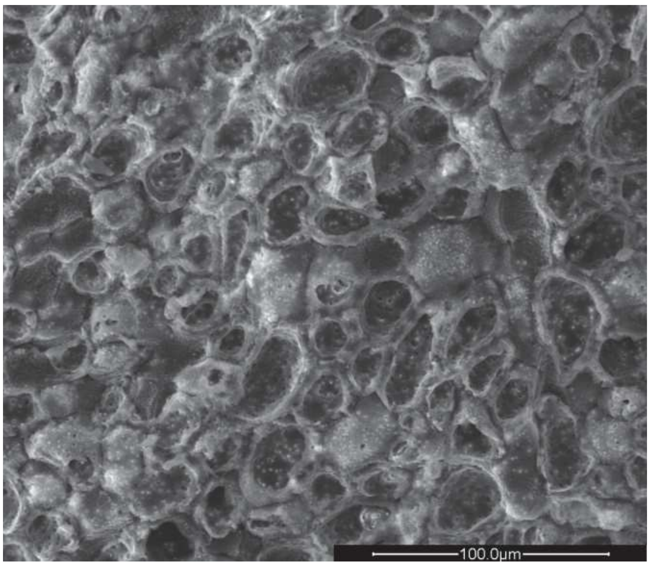


*Fig. 3a. SEM image of crushed peach shells (PS), 1000x*

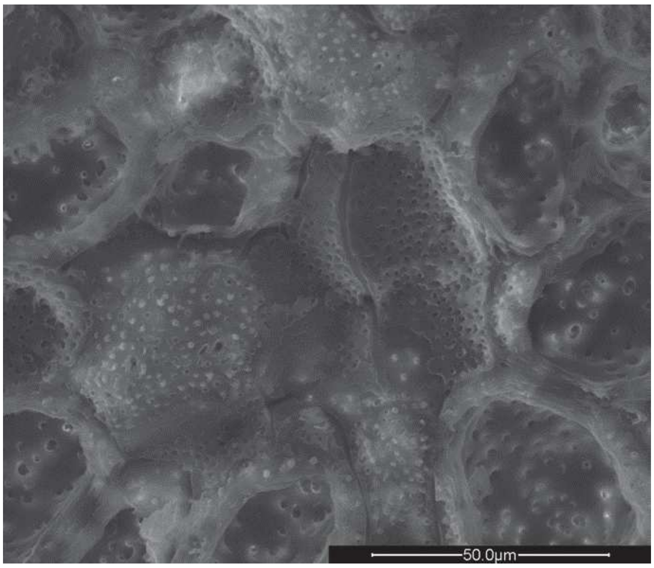

*Fig. 3b. SEM image of crushed peach shells (PS), 2000x*

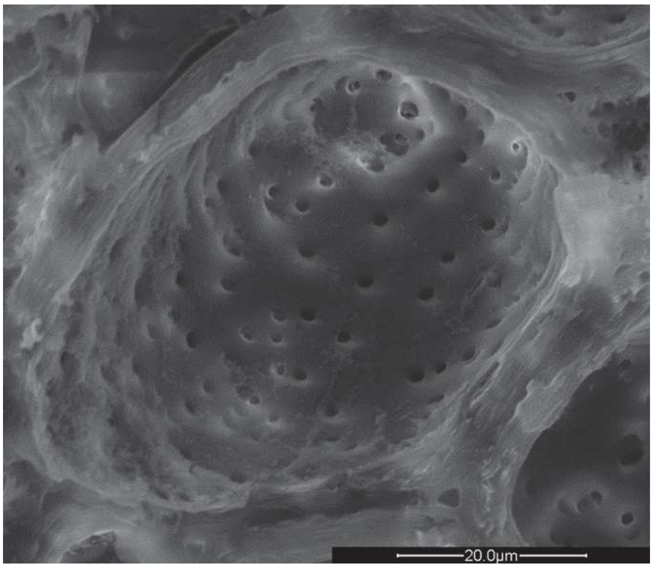

*Fig. 3c. SEM image of crushed peach shells (PS), 4000x*

The surface appears rough, irregular and have many ovoidal cavities. The grater diameter of the cavities is approximately 50 µm, and the smaller is about half, 25 µm. Microporosities extend over the entire external surface and inside the cavities. Their size was approximately 2.0 µm. The high number of microporosities gives the peach shells a low density but, at the same time, leads to a greater absorption of water by inclusion.

### 3.3. Density and compressive strength of the LWC samples

Based on the ACI Committee 213 Guide for Structural Lightweight Concrete, LWC can be classified by its density, typically ranging from 320 to 1920 kg/m$^3$ [58]. This density-based classification produces three material groups: *i*) low-density concretes (300 – 800 kg/m$^3$); *ii*) moderate-strength concretes (800 – 1350 kg/m$^3$); *iii*) structural concretes (1350 – 1920 kg/m$^3$). Additionally, these three classes are related to specific strength levels: 0.7–3.4 MPa; 3.4-17 MPa; and 17-63 MPa, respectively [59,60]. Density is crucial as it determines several characteristics and properties of concrete, including compressive strength [61]. Reducing concrete density leads to an increase in its porosity, a decrease in thermal conductivity and typically a decrease in mechanical strength.

The density data obtained are collected in Table 5.

Table 5

Demoulded, Air-dry, and Oven-dry density values of LWC samples

| Density (kg/m$^3$)* | | | |
|---|---|---|---|
| **Sample** | **Demoulded (24 h)** | **Air-dry (28d)** | **Oven-dry (28d)** |
| ***PS_a*** | *1207.4 ± 1.5* | *1107.7 ± 1.4* | *1031.9 ± 1.4* |
| ***PS160_a*** | *1212.7 ± 2.0* | *1112.9 ± 1.7* | *1038.7 ± 1.8* |
| ***PS200_a*** | *1192.9 ± 1.3* | *1093.6 ± 1.2* | *1012.4 ± 1.3* |
| ***PS240_a*** | *1187.4 ± 1.5* | *1088.9 ± 1.5* | *1009.7 ± 1.4* |

| | | | |
|---|---|---|---|
| ***PS_b*** | *1464.5 ± 0.9* | *1295.2 ± 0.8* | *1204.8 ± 0.7* |
| ***PS160_b*** | *1469.7 ± 1.1* | *1300.8 ± 1.2* | *1209.5 ± 1.3* |
| ***PS200_b*** | *1453.5 ± 1.9* | *1289.6 ± 1.8* | *1184.6 ± 1.9* |
| ***PS240_b*** | *1448.3 ± 1.5* | *1284.6 ± 1.4* | *1177.3 ± 1.5* |

*Data are expressed as mean of three replicates ± SD

All the samples were in the density range related to moderate-strength LWC. As expected, the density value decreased as the roasting temperature increased, which is in line with the bulk density trend of the peach shells (Table 2). However, unexpectedly, the PS160 samples did not follow this trend, as the PS samples have lower density values, regardless of the binder mixture. This difference may be due to the higher water absorption observed following heat treatment at 160 °C, which probably resulted in the higher density of LWC. Therefore, a temperature higher than 200°C is required to induce a modification of the lignocellulosic matrix obtain a significant decrease in the density of LWC.

The use of lime as a binder in concrete leads to a lower density than cement-based concrete, because of its lower specific gravity and bulk density [62]. This is confirmed by the higher density values observed in the specimens prepared with the binding mixture "b", containing cement. Furthermore, the values of Table 5 are all significantly lower than those reported in other studies relating to cement-based LWC prepared with similar vegetable matrices as lightweight aggregate [34,63,64].

The density is also influenced by the amount of air trapped inside the concrete, a phenomenon that can be caused by several factors. Generally, the irregular shape of the aggregates and, in particular, the flaky shape, hinder the complete compaction of concrete, thus contributing to a higher trapped air content, higher porosity, and decreasing density [65]. Moreover, lightweight aggregates trap air inside due to their high porosity.

The results of compressive strength tests at 28 and 56 days of the LWC samples are shown in Table 6.

Table 6

Compressive strength at 28-day and 56-day of LWC samples

| Compressive strength (MPa)* | | |
|---|---|---|
| **Sample** | **28-day** | **56-day** |
| ***PS_a*** | *1.38 ± 0.20* | *1.99 ± 0.14* |
| ***PS160_a*** | *1.21 ± 0.11* | *1.78 ± 0.16* |
| ***PS200_a*** | *1.92 ± 0.17* | *2.63 ± 0.20* |
| ***PS240_a*** | *2.23 ± 0.15* | *2.92 ± 0.17* |
| ***PS_b*** | *4.01 ± 0.16* | *4.97 ± 0.21* |
| ***PS160_b*** | *3.75 ± 0.15* | *4.59 ± 0.16* |
| ***PS200_b*** | *4.68 ± 0.11* | *5.51 ± 0.12* |
| ***PS240_b*** | *4.99 ± 0.17* | *5.88 ± 0.16* |

*Data are expressed as mean of three replicates ± SD


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The compressive strength of all the specimens prepared with the binder mixture "a" have a compressive strength of less than 3.4 MPa. Therefore, these specimens are not classified as "moderate-strength concrete", because of their insufficient compressive strength. However, their application potential is not limited by this classification system. For example, for some applications, such as for non-structural mortar beds for wooden floors, density values typical of moderate-strength concrete are recommended, but compressive strength values higher than 3.4 MPa are not required [37]. On the other hand, the compressive strength of the specimens containing cement, prepared with the binder mixture "b", had compressive strength values higher than 3.4 MPa, and perfectly meet the requirements of moderate-strength concrete. There are countless potential uses for these materials [25,66], but their most practical application is as a non-structural fill for thermal and sound insulation in floors and roofs.

The compressive strength of concrete is influenced by several factors, including the properties and volume of aggregates [67,68]. In particular, porosity and water absorption have a significant influence, as they make concrete less compact and porous. The lower water absorption of the peach shells roasted at 200 and 240 °C explains the greater compressive strength of the specimens PS200 and PS240. Similarly, the greater water absorption found in peach shells treated at 160 °C compared to naturally dried peach shells justifies the decrease in compressive strength observed when passing from the PS sample to PS160.

## *3.4. Thermal Conductivity coefficient of the LWC samples*

Thermal conductivity plays a crucial role in the design and use of non-structural lightweight concretes. With the world facing a climate crisis, insulating materials have become increasingly popular [14,69]. Energy efficiency in buildings is gaining momentum, and strategies are being developed to ensure that buildings consume less energy. Boosting the thermal insulation of a building is key to achieving this goal, as it helps enhance energy efficiency, which is crucial to ensuring a sustainable future [9,70]. In fact, enhancing thermal insulation can lead to significant reductions in environmental impact and $CO_2$ emissions, as air conditioning, ventilation, and occupant comfort account for approximately 29% of the $CO_2$ emissions from the building sector.

The thermal conductivity of concrete is influenced by several factors, such as the type and content of the aggregates, the content of air voids, the distribution of pores and their geometry, the moisture content, the w/b ratio and the type of binding mixture [71]. For example, the thermal conductivity of conventional concrete is inversely proportional to the porosity content [72]. This factor is particularly significant as air has low thermal conductivity (0.025 W/mK at room temperature). Therefore, microstructural factors strongly affect this property.

The results are collected in Table 7

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Table 7
Thermal conductivity of LWC samples

| Sample | Thermal conductivity coefficient (W/mK)* |
|---|---|
| ***PS_a*** | *0.15 ± 0.01* |
| ***PS160_a*** | *0.19 ± 0.03* |
| ***PS200_a*** | *0.09 ± 0.04* |
| ***PS240_a*** | *0.03 ± 0.01* |
| ***PS_b*** | *0.20 ± 0.01* |
| ***PS160_b*** | *0.29 ± 0.05* |
| ***PS200_b*** | *0.15 ± 0.03* |
| ***PS240_b*** | *0.10 ± 0.04* |

*Data are expressed as mean of three replicates ± SD

The results show that there is a significant difference in the thermal conductivity properties between the samples made with naturally dried peach shells (PS) and those made with thermally treated shells (PS160, PS200, and PS240). It is evident that the thermal conductivity coefficient decreased with an increase in the temperature at which the shells were treated, except for roasting at 160 °C. In fact, PS160 has a higher thermal conductivity coefficient than PS, demonstrating a significant correlation between LWC density and thermal conductivity. However, the thermal conductivity of peach shell concrete is low, because of the highly porous structure of the lightweight aggregates, which carry more air bubbles into the concrete during the mixing phase. The addition of cement (mixture "b") resulted in better compactness of the samples and a consequent worsening of their thermal insulation properties.

Moderate-strength concrete generally has a thermal conductivity coefficient between 0.2 and 0.6 W/mK [73,74]. Table 7 reveals that all samples fall within this range or exhibit even lower values, demonstrating stronger insulating properties. The samples produced using mixture "a" possess a thermal conductivity coefficient lower than 0.2. This suggests that the use of lime as a binder enhances thermal insulation. Although this binder resulted in less dense and mechanically weaker specimens, it yielded lighter and more thermally insulating

## 4. Summary and conclusions

The potential of peach shells as lightweight aggregates in the production of eco-friendly LWC was evaluated:

- The shells were air-dried and roasted at different temperatures (160, 200, and 240°C). Heat-treated shells at temperatures higher than 200 °C showed lower bulk density, specific gravity, and water absorption, whereas those treated at 160 °C showed an increase in these physical properties compared to untreated peach shells.
- The specimens containing only lime as a binder were more eco-friendly, as lime is more


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ecological than cement, lighter, and more thermally insulating.

- The compressive strength was low, falling below the threshold of 3.4MPa required for "moderate-strength concrete". However, this did not diminish its application potential. Samples containing cement (mixture "b") had a higher compressive strength, fitting the classification of "moderate-strength concrete".
- Samples containing cement (mixture "b") had a higher coefficient of thermal conductivity, while lime-based concrete showed better insulating properties. In general, all specimens had a low thermal conductivity thanks to the high porosity of the peach pits, as evident from the SEM analysis.
- Heat treatment improved properties, such as density, compressive strength, and thermal insulation, but only at temperatures above 200°C. At 160°C, the treatment was inadequate for triggering useful changes in the cellulosic fraction of the shells. Aggregates treated at higher temperatures resulted in a significant reduction in water absorption, which improved the properties of concrete.

The findings of this study have significant implications for the construction industry by providing a sustainable solution to reduce waste, lower energy consumption, and mitigate the environmental impact of traditional construction materials. Future investigations could focus on optimizing the heat treatment parameters to achieve even greater enhancements in the properties of peach shell-based lightweight concrete, such as fine-tuning the roasting temperature and duration. Considering the low compressive strength exhibited by lime-based specimens, future studies could investigate reinforcement techniques or the addition of supplementary materials to enhance the mechanical properties while preserving the eco-friendliness of our lightweight concrete.

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## Author contributions

Conceptualization [V.D.; S.P.]; methodology [V.D.; B.A.; A.U.]; software [V.D.; A.M.]; validation [A.M.; F.R.]; formal analysis [A.M.; S.P.]; investigation [V.D.; B.A.; A.U.]; resources [A.M.; S.P.; F.R.]; data curation [V.D.; S.P.]; writing—original draft preparation [V.D.]; writing—review and editing [V.D.; A.U.; B.A.]; visualization [V.D.; F.R.]; supervision [A.M.; S.P.; F.R.]; project administration [V.D.; A.M.]; funding acquisition [A.M.; S.P.].

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## Conflict of interest

The authors declares no conflict of interest

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# An Ethnographic Study on the Cognizance of the Higa-onon Youth about their Native Language

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## Abstract

Speaking a native language expressed a kind of art. The people in Bukidnon primarily speak various languages that contributes to the linguistic diversity of Mindanao, Higa-onon being one of those languages. Speaking the native language is one way of preserving culture. However, with the passage of time and the new social and cultural trends and development, the native language seems to be cast aside by the younger generation. Preserving the Higa-onon tribe's native language enables more meaningful communication and respect for these ties and the legacy of the culture. The study aimed to examine the Higa-onon youths' conservation of the native language. The study uses a descriptive explanatory design to investigate the perceptions and experiences of six Higa-onon students (five males and one female) in learning the native language. The study used a validated questionnaire and conducted semi-structured interviews to collect relevant data from respondents, which were analyzed thematically. The study found that learning the Higa-onon dialectal helps preserve the language and Indigenous culture. The Higa-onon language preserves native stories and community standards. Higa-onon pride comes from language preservation. Moreover, learning Higa-onon made the participants value the language and realize their culture.

**Keywords: Higa-onon Language; Native language; Indigenous language; Ethnographic study**

# Introduction

## 1.1. Background of the study

There is an importance in speaking the native language, which many consider an art form. Many languages are spoken in Mindanao, mainly by indigenous people in Bukidnon. The native language is vital for preserving the culture. From generation to generation, speaking the local tongue is becoming unrecognized and fading with time. It endangers Bukidnon culture's foundational practices. Many schools encourage students to experience other cultures, which preserves rich knowledge, traditional wisdom, and artistic and creative expressions and ensures the longevity of the native language (Ethnologue, 2015). However, the decline of language practice is becoming a problem among the youth, not just by their lack of recognition as members of their native group. At the same time, the influence of this new generation is constantly affecting the native culture (United Nations, 2016).

Preserving the native language of the Higa-onon tribe allows for more meaningful communication that can facilitate respect for these relationships and the heritage culture as a whole (Treibold, 2020). The United Nations (2016) confirmed that Indigenous languages worldwide are in danger of dying out, with one dying out every two weeks and many more at risk. In addition, the study concerned the Philippine languages of the archipelago's 175 Indigenous languages, endangering 35 and 11 are on the brink of extinction, specifically focusing on the Higa-onon language (Saranza, 2016; Villasin-Young, 2022). The researcher attempts to determine how the native language affects current institutions.

The study anchors on the theory of Manuel (1969) that language is inseparable from a person's daily life and culture. It is through our language that we show who we are. The disappearance of the Higa-onon language risks the whole socio-cultural foundations of our community of speakers. In this study, the researcher finds two variables in connection to the importance of the native language. The first variable, speaking the Higa-on language, refers to speaking the learning language. Second is that speaking the language is credentialed to an individual using language as such.

The primary purpose of this study is to address the gap in knowledge of Higa-onon language preservation in today's generation. Many younger generations are shifting towards using widely spoken languages, such as English, instead of their native tongue. This gap in knowledge and understanding of ancestral languages has resulted in the loss of cultural heritage and traditions, with many indigenous languages being on the brink of extinction. The issue of native language preservation has become increasingly important as people recognize the valuable insights and knowledge that can be passed down through language and culture.

## 1.2. Statement of the problem

The study investigates the Higa-onon language conservation among selected Higa-onon students in San Isidro College. This research addressed the importance of learning and speaking the Higa-onon language in today's generation. Specifically, it answers the following;

What are the perceptions of the present Higa-onon youth regarding the native language?

What are the experiences of the present Higa-onon youth in learning the language?

## 2.1. Research design

The study uses a descriptive explanatory design following an ethnographic method to investigate the concept of the study (Creswell & Cresswell, 2017) regarding the learning and use of the Higa-onon language in today's generation. The study investigates the Higa-onon student's perception of the importance of speaking the native language among youth. Although there are other languages of the native tribes of Bukidnon, the study focuses only on the language of the Higa-onon tribe.

## 2.2. Sample and sampling technique

The study used a non-probability criterion sampling to identify the participants who would participate. The criterion for selecting the participants was a bonafide student of San Isidro College and a native speaker of the Higa-onon language (Cohen & Crabtree, 2006). This study focuses on the importance of the native language inherited by the Higa-onon tribe. Language is essential in employing personal identity and will make many opportunities to promote their cultural traits such as clothing and religious rituals.

The researchers interviewed six (6) students for the study. All participants are college students who agreed to provide their narrative and experience in learning the Higa-onon language as a member of the tribe with the researchers. Each participant completed a personal information form, as shown in Table 1.

**Table 1.**
*Self-described profile of the participants*

| Participant | Gender | Ethnicity | Age (years) | Extent of Ethnicity |
|---|---|---|---|---|
| H1 | Male | Higa-onon | 22 | Pure Native |
| H2 | Male | Higa-onon | 23 | Pure Native |
| H3 | Male | Higa-onon | 25 | Pure Native |
| H4 | Male | Higa-onon | 24 | Half Native |
| H5 | Male | Higa-onon | 22 | Pure Native |
| H6 | Female | Higa-onon | 21 | Pure Native |

Table 1 shows that of the six (6) participants, five (5) were males, and one (1) was female. All six (6) participants were members of the Higa-onon tribe. The average age of the participants was 23 years old (the youngest was 21 years old, and the eldest was 25 years old). Of the six (6) participants, five (5) are pure-blooded native members of the tribe, and one (1) is a half-blooded native.

## 2.3. Research instrument

The research used a researcher-made questionnaire to gather relevant information regarding the study – experts validated the content – gauging the students' perception of the Higa-onon language in today's generation. The study focuses on exploring learning the Higa-onon language of college students; this study clustered the interview questions into two distinct but interconnected thematic categories to help with the first step of thematic content analysis. The first section of the interview explored the thematic category of each participant's perceptions of learning the Higa-onon language from their personal opinions. The second interview category focused on the participants' experience learning the Higa-onon language. At the end of the interview, the researchers explicitly checked with each participant to find out if they were satisfied with their responses or needed to add anything more to their narratives.

## 2.4. Data gathering procedure

The study followed an in-depth semi-structured interview format (Yin, 2014) to allow the participants to respond to the interview questions freely from their points of view and to express the importance of the Higa-onon language among the youth. Moreover, the study employed ethnographic interviews, an appropriate research process in a complex and sensitive field of research (Chatterjee & Kumar, 1999) such as the current study. The method collected the participant's narratives and responses to learning the Higa-onon language. The researcher recorded the individual interview sessions with the participants. The interview schedules took between 21 and 29 minutes to complete. The researchers transcribed the interviews into printed transcripts. Each participant had the opportunity to read through their interview transcripts, discuss any discrepancies with the researcher, and approve the accuracy of the transcript from their perspective. This study obtained written consent from each participant giving their permission to record the interview session on a recorder.

## 2.5. Data analysis

The study focused on the Higa-onon students' perception of the language in the 21st century. The study categorized the participant's responses into a familiar concept using thematic data analysis. The study analyzed the data following two steps. First, the researchers organized the data into categories using the discourse-neutral thematic content analysis method (Wilbraham, 1995). The step involved coding the texts into thematic categories of content-based themes around the narratives of learning the Higa-onon language. The second step involved applying the deconstructive critical discourse analysis, which involves reading the interview texts of the participants (Fairclough, 2003). The step explores and understands each participant's narratives within the context of learning the Higa-onon language. The text used in the analysis is copied verbatim and translated into English with the help of A Higa-onon member.

# 3. Results and discussion

The research was conducted to study the perceptions and experiences of the Higa-onon youth in learning the native language. The study explored the perceptions of the importance and contribution of the Higa-onon language in modern times and their experience in learning the language. The study used frequencies and percentages to treat the data and analyzed the narrative responses qualitatively of the participants.

### 3.1. Perception of the Higa-onon youth of the native language

The first thematic category of the perceptions of learning the Higa-onon language among the youth focuses on exploring the participants' insights as they made sense of the importance of the language and the contributions of understanding the language in the 21st century and the community. The development of a personal narrative about the significance and contribution of the Higa-onon language to the community was prevalent in the interviews.

Table 2 summarizes the responses of the Higa-onon youth regarding their perception of the importance of learning the native language. The responses were categorized into similar themes. It can be observed from the result that seven (7) themes were formed from the response of the students.

**Table 2.**

*Summary of the importance of the Higa-onon language*

| RESPONSE CLUSTERED INTO THEMES | PARTICIPANT | *f* | % |
|---|---|---|---|
| Preservation of the language | H1, H2, H3, H4, H5, H6 | 6 | 100 |
| Promotion of the Indigenous culture | H1, H3, H4 | 3 | 50 |
| Preservation of native stories | H1 | 1 | 17 |
| Upkeep of the native community standards | H1, H2 | 2 | 33 |
| Mother-tongue of the community | H3 | 1 | 17 |
| Employment in a native community | H2 | 1 | 17 |
| Sense of pride for the Higa-onon tribe | H5 | 1 | 17 |

Within the thematic category of perceptions of learning the Higa-onon language, seven (7) themes emerged under the importance of learning the language. All of the 6 (100%) participants stated that it is crucial to preserve the language.

**H3:** *… Mas madagway ko hadi malipatan sa binukid ha inikagiyan, mas madagway gane ko itudlo pa tungkay hu mga laas taw sa binukid doon hu mga bata dan daw hu mga apo dan.*
*(…it must not be lost when the time comes, or the Higa-onon language must be enhanced as a language, and it must be known to the next generation.)*

**H4:** *… Mas madagway gane ko makatuon sa mga kabataan mug ikagi binukid bisan ko kona sidan tungkay ha Higa-onon.*
*(…it is also very important to for them (youth) to know Higa-onon, even though they are not born pure Higa-onon.)*

**H6:** *… Bisan iman ko bag o on sa henerasyon mas madagway gihapon ko makatuon ki mug ikagi hu binukid.*
*(…that is because, even if the trend is different because of modernity, it is still important to learn this (Higa-onon) type of language.)*

Several participants (H1, H3, and H4) highlighted the importance of the language as it promoted the Indigenous culture. Underlying these statements, many cultures have integrated with the locality, and learning the culture of one tribe is not that difficult as multicultural communities have expanded in the 21st century (Mila et al., 2021).

**H1:** *Labi on gayud ta madakol pa gihapon sa mga Higa-onon dini ta Bukidnon ha panday dan pig timaan sa pagka Higa-onon dan. …*

*(That is because there are many Higa-onon here in Bukidnon. And it promotes the culture of the Higa-onon)*

Two participants (H1 and H2) stated that language helps keep community standards and practices that can only be expressed and practiced in the native language.

**H1:** *… Ta ko amin no mabuhat ha kona madagway maapil no pa sa duma ha utaw/ daw ko hindu ka tag tima maapil pa sidan. Inuhon no pagpasabot ko bisan gane sa inikagiyan dan hadi ka pakatuon. Hadi no ug ka tuin an sa inikagiyandan; ko ino sa igpasabot no…*
*(…if you do something bad, it will bring harm to the community, So, if you don't know the language, how will you defend the ideas to them…)*

For some participants, the other important aspect of learning the language are as follows: Preservation of native stories (H1):

**H1:** *… madakol sa mga nanangon ha amin ta ug katun-an daw mga laos ha mga inikagi gabi hu mga laas ha anay ha dun ta ug katun-an hu mga Higa-onon daw Kandan da gayud hayan…*
*(…there are many stories, lessons, and truth that can only be uttered in the native language.)*

Mother tongue of the community (H3):

**H3:** *… sa binukid man gud iyan man gud unta hayan ug gamiton taw ha ini kagiyan dini ta Bukidnon…*
*(…the Higa-onon language if we associate it with Bukidnon it it's the mother tongue. That should be the dialect…)*

Employment in a native community (H2):

**H2:** *… importante tungkay ha makatuon ka mug binukid labi on gayud ko doon ka makapayaon hu lugar ha kabayaan no ha doon ka magtrabaho…*
*(…it is very important especially when you are assigned to a place where you want to work…)*

Sense of pride for the Higa-onon tribe (H5):

**H5:** *… mas madagway ko hadi ta ikagayha sa pagka Higa-onon ta…*
*(…we should not be ashamed being a Higa-onon…)*

Learning the Higa-onon language is crucial because it enables an individual to communicate effectively with those who speak it. The knowledge promotes understanding and mutual respect, improving relations, facilitating diplomacy, and fostering community cohesion. Preserving native languages is essential because they are often part of a community's heritage and cultural identity. Losing a language can have far-reaching consequences, including losing traditional knowledge, customs, and values unique to that community. Maintaining local dialects in modern times is also essential because they offer a unique perspective on history and culture (Alejan et al., 2021; Bonifacio et al., 2021). These dialects often contain words and phrases specific to a particular region and reflect the community's way of life. In short, learning the Higa-onon languages and dialects is crucial to preserving cultural diversity, promoting mutual respect, and providing insight into the human condition (Mila et al., 2021).

Table 3 summarizes the responses of the Higa-onon youth in their perception of the contribution of learning the native language. The responses were categorized into similar themes. It can be observed from the result that four (4) themes were formed from the response of the students.


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**Table 3.**

*Summary of the contribution of the Higa-onon language*

| RESPONSE CLUSTERED INTO THEMES | PARTICIPANT | *f* | % |
|---|---|---|---|
| Breaks the boundaries of communication | H1, H2, H5, H6 | 4 | 67 |
| Promotes understanding of the culture and language | H1, H4 | 2 | 33 |
| Creates the identity of the Higa-onon tribe | H3 | 1 | 17 |
| Preserves the local culture | H4 | 1 | 17 |

Within the thematic category of perceptions of learning the Higa-onon language, four (4) themes are under the contribution of learning the language. Four (4) participants stated that learning the language breaks communication boundaries.

**H1:** *… ko pakatoon ka mug ikagi hu binukid madakol sa agka gamitan kona bada inikagiyan daw pagpakig storya. Paka bulig tungkay ta kanit ko inu sa boot daan ig pasabot daw ko inu sa Kandan ug katun-an. Pakabulig daan ha malaag sa pagkabaligayhanon dan…*
*(…speaking the native language, primarily helps in communication. But not only in communication, but also in the exchange of ideas and in breaking communication boundaries…)*

**H5:** *…communication is important because it is a way to communicate and other people especially with Higa-onon tribe.*

For some participants, the other contributions of learning the language are as follows: Promotes understanding of the culture and language (H1 and H4):

**H4:** *… Iling taiya pagsaulog taw hu kaamulan pakabulig panday ho matun-an taw sa mga kultura dini ta Bukidnon kona iyan da sa Higaunon ta madakol pa baya sa kultura dini ta Bukidnon*
*(…just like celebrating the Kaamulan, it helps in understanding the different cultures here in Bukidnon…)*

Creates the identity of the Higa-onon tribe (H3):

**H3:** *… kanit man gud haiya ha inikagiya, dini ta Bukidnon, kona man gud haiya don ku duma ha kultura kanit man gud haiya. Dapat makatuon ki mug ikagi hu binukid.*
*(…this is our (Higa-onon) language, it is in Bukidnon, this is not the culture of others. So we must learn the language.)*

Preserves local culture (H4):

**H4:** *… sa inikagiyan ha binukid panday paka bulig hu pag Lalang daw pagka langana; labi on gayud sa Higaunon panday paka bulig Kandan ku pag kalangana dan…*
*(…in speaking the language, it helps in preserving the culture and preserve the truth of being a Higa-onon…)*

Learning the Higa-onon language has numerous benefits for both individuals and society. Developing proficiency in the Higa-onon language helps to preserve cultural heritage and promote cultural diversity. It also strengthens the sense of identity and pride within a community. Additionally, speaking the Higa-onon language can improve communication and understanding among community members and enhance social cohesion. Learning the Higa-onon language is an investment in local communities cultural and social well-being (Alejan et al., 2021; Bonifacio et al., 2021; Mila et al., 2021).

## 3.2. Experience of the Higa-onon youth in learning the native language

The second thematic category is the participants' experience of the youth learning the Higa-onon language, focusing on exploring their methods as they learn the language in the 21st century. The development of the participants' narratives differs in their experience in learning the Higa-onon language was prevalent in the interviews.

Table 4 presents the summary of the experience of the Higa-onon youth in their learning of the native language. The responses were categorized into similar themes. It can be observed from the result that five (5) themes were formed from the response of the students.

**Table 4.**

*Summary of the experience of the Higa-onon youth in learning the native language*

| RESPONSE CLUSTERED INTO THEMES | PARTICIPANT | *f* | % |
|---|---|---|---|
| Realizations of my own culture | H1, H4 | 2 | 33 |
| Valuing the language | H1 | 1 | 17 |
| Difficult to learn | H3, H4 | 2 | 33 |
| Determination makes learning the language easy | H2 | 1 | 17 |
| Family and community influences language learning | H2, H3, H4, H5, H6 | 5 | 83 |

Within the thematic category of experiences in learning the Higa-onon language, five (5) themes are under the contribution of learning the language. Five (5) participants stated that in learning the Higa-onon language, their families and community had influenced their learning of the native language.

**H3:** *… Natimo ko da daan haiya doon ho pigtimaan ko ta madakol ta Kandan mga Higaunon daan…*
*(…from my own experience, I just adopted because of the society where I belong. Because mostly, the community are Higa-onon…)*

**H4:** *… Sa kanak laus ha pamilya; ko tag Lalang sidan, Si inay daw si amay, say apo, daw say booy ko tag kalangana sidan binukid man…*
*(…But for me, when my family converse with each other, my mother and father, my grandmother and grandfather talk to each other before in Higa-onon…)*

**H6:** *… bisan ha atyuay apa ko tag kalangana ta diya balay tag binukid kay, ta si inay daw si amay tag binukid man daan…*
*(…when I was young, I already know because my mother and father talk to us in Higa-onon already…)*

For some participants, the other experiences of learning the language are as follows: Realization of my own culture (H1 and H4):

**H1:** *Sa pinaka una gayod madakol sa ug katun-an ko ha ug ka aha ko doon hu kanit ha kultura…*
*(The first thing is you will realize many things and make connections of your own culture…)*

Difficult to learn (H3 and H4):

**H4:** *sa kanak ha naagiyan sa pug kinanao hu binukid; panday tungkay malugon. Lugay a panday nakatuon madakol panday sa ug paman-agbol daw apa nakatuon…*

*(Well, my experience in learning the Higa-onon language, it is not easy…It takes time for me to learn… )*

Valuing the language (H1):

**H1:** *… Ugka ugsakan no panday kahulugan sa natun-an no ta ug kaaha nu Kandan ha panday dan gayud pigtimaan sa pagka Higaunon dan…*
*(…you give more value to the language you practice because you will expand what you will learn from the Higa-onon…)*

Determination makes learning the language easy (H2):

**H2:** *… kona on panday malugon ta kanak sa pugkananao hu binukid. Kona man malugon sa pugkinanao hu binukid dependi da gayud hayan hu utaw ko mabaya mug kinanao hu binukid…*
*(…it not anymore a challenge for me to learn Binukid. It is easy to learn, it is up to the person if they are determined to learn…)*

Generally, the study observed that Higa-onon youths have varying experiences in learning their native dialects. Some may have been exposed to the Higa-onon language early on and developed strong language skills. Others may have only been exposed to the Higa-onon language later in life, causing difficulties in developing proficiency. The family and community significantly impact the learning of the Higa-onon language by providing support and creating an environment for its use. When the family and community regularly use the native language in their daily lives and encourage its use. In that case, the youths are likelier to continue developing their language skills. Additionally, cultural events and celebrations can promote and preserve the Higa-onon language as an essential part of the community's identity (Alejan et al., 2021; Bonifacio et al., 2021; Mila et al., 2021).

## 4. Summary and conclusions

The study ascertained the importance of learning the Higa-onon language to preserve the language and promote the Indigenous culture. Additionally, the language helps in preserving native stories and community standards. Preserving the language creates a sense of pride for the Higa-onon tribe. Learning Higa-onon helps people converse with others who speak it. Knowledge fosters understanding, respect, diplomacy, and community unity. Native languages are often part of a community's traditions and culture. Losing a language can lead to losing a community's traditions, customs, and values. Native dialects offer a distinct viewpoint on history and society; hence they must be preserved. These dialects reflect the communities' way of life. Knowing the Higa-onon languages and dialects is essential to conserving cultural diversity, encouraging mutual tolerance, and understanding our shared human experience.

Moreover, the language helps break the boundaries of communication, promotes the understanding of the local culture, and creates the identity of the Higa-onon tribe. Individuals and society benefit from learning the Higa-onon language. Higa-onon language proficiency preserves cultural heritage and promotes cultural diversity. It strengthens community pride and identity. Overall, understanding Higa-onon improves local communities' cultural and social well-being.

The participants' experiences learning the Higa-onon language made them value the language and helped them realize their sense of culture. However, learning the language is a complicated process, but


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determination and community influence help in learning the Higa-onon language. The overall finding indicates that the answer varies from one participant to another. Nonetheless, the participants have their perceptions and experiences in learning the Higa-onon language. Higa-onon youth learn their local dialects differently. Some may have learned Higa-onon as children. Others may have been introduced to Higa-onon later in life and have difficulty learning the language—family, and community significantly impact by supporting and fostering Higa-onon language use.

The result of the study helps guide the learning of the Higa-onon language as an evidence-based strategy to improve the preservation of the Higa-onon language and the native Bukidnon language as a whole. Also, the study provides rich evidence-based research, especially on the perceptions and experience of learning the Higa-onon language of the youth in the 21st century. In addition, the research paper provides additional knowledge to the dearth of literature on learning the Higa-onon language or, generally, the native Bukidnon Language as a whole. The study recommends to explore other perceptions of the youth on the language of tribes of Bukidnon.

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## Author contributions

Conceptualization [J.C.]; methodology [J.C.]; validation [E.T.]; formal analysis [J.C.]; investigation [J.C.]; data curation [J.C.]; writing—original draft preparation [J.C.]; writing—review and editing [E.T.]; visualization [J.C.]; supervision [E.T.]; administration [J.C.]; funding acquisition [E.T.]

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## Conflict of interest

The authors declares no conflict of interest



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