CURRENT RESEARCH FROM SCIENCE TO TECHNOLOGY-II

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This book is dedicated to the 50th anniversary of Sivas Cumhuriyet University.

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PREFACE

Universities, research institutions, and R&D centers conduct studies to provide a better future, achieve prosperity, foster societal development through collaborations, and create a strong ecosystem. The purpose of this book is to contribute to the established ecosystem by providing examples in areas such as environment, health, and materials. This book highlights current research efforts.

This book includes current topics such as “Weak Isospin Invariance: Another Aspect of Fermion Compositeness,” “Green Extraction Methods,” “The Muon Collider and Some of Its Applications on New Physics,” and “Advanced Oxidation Methods for a Sustainable Environment: Innovative Approaches in Wastewater Treatment” and “Optimized Crops for The Soil with Artificial Intelligence Techniques Forecast”

As science and technology progress at a dizzying pace, this book is intended to assist researchers and engineers.

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CHAPTER 1

WEAK ISOSPIN INVARIANCE: ANOTHER ASPECT of FERMION COMPOSITENESS

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INTRODUCTION

The Standard Model (SM) of particle physics is a mathematical model that describes the electromagnetic, strong and weak interactions among elementary particles and it is a local gauge theory expressed by the gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$. SM has a perfect confirmation with the experimental data coming from the particle accelerators. The elementary particle spectrum of the SM appears as a three-generation structure for two types of fermions called quarks and leptons. According to SM scheme fermions are assigned to left-handed weak isospin doublets ($I_W = 1/2$), and rigt-handed weak isospin singlets ($I_W = 0$). The classification of three generations of SM fermions according to weak isospin multiplets is given in Table 1. Also, gauge fields belong to isospin multiplets with $I_W = 0$ or 1 ($I_W = 0$ for photon and gluon or $I_W = 1$ for $W^{\pm}$ and Z bosons).

Except for their particle masses, these generations are copies of each other. Although the SM is well compatible with experimental data, there are some issues for which it cannot provide an answer, such as replication of fermionic families, matter-antimatter asymmetry, neutrino masses, dark matter, etc. The idea that there are sub-building blocks more fundamental than quarks and leptons provides a natural explanation for the SM fermionic family replication. Models beyond the SM that consider a layer of more fundamental building blocks are composite models, in which the elementary particles in the SM are treated as bound states of more fundamental constituents called preons [1-3]. By considering SM fermions as the ground state, observation of excited fermionic states would be a direct evidence if leptons and quarks have a composite structure [4-8]. Excited fermions are also thought to have three generations, with similar properties to SM fermions. Spin and isospin-1/2 excited fermions are considered as lowest radial and orbital excited states. Both right-handed and left-handed components of excited spin-1/2 fermions can be present in isodoublets, so their couplings with the gauge fields are of vector type [9]. Also, the Lagrangian describing the interaction between the excited fermion, the SM fermion and the gauge boson must be of magnetic transition type in order to remain invariant under $SU(2)_L$[8-10]. Excited fermions with spin and isospin-1/2 are studied widely in the literature [9- 31].

It is also possible to search for compositeness from a different perspective by taking into account the weak isospin invariance. By the extended weak isospin model, usual isospin values (singlets with $I_W = 0$) and (doublets with $I_W = 1/2$) are extended to include $I_W = 1$ (triplet) and $I_W = 3/2$ (quadruplet) values. The basics and details of the extended isospin model are given in [32]. The most characteristic feature of the extended weak isospin model is that it has excited fermions with exotic electrical charges ($Q = -2e$ for the lepton sector and $Q = 5/3e$ and $-4/3e$ for the quark sector). These excited fermions that have $I_W = 1$ and $I_W = 3/2$ values are least studied in the literature.

Table 1. Weak Isospin Multiplets of SM Fermions

Fermion	1st Generation		2nd Generation		3rd Generation	
	$I_W = 1/2$	$I_W = 0$	$I_W = 1/2$	$I_W = 0$	$I_W = 1/2$	$I_W = 0$
Leptons	$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_L$	e_R	$\begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_L$	μ_R	$\begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_L$	τ_R
Quarks	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	u_R, d_R	$\begin{pmatrix} c \\ s \end{pmatrix}_L$	c_R, s_R	$\begin{pmatrix} t \\ b \end{pmatrix}_L$	t_R, b_R

The classification of three generations of SM leptons and quarks according to weak isospin multiplets.

BASICS of EXTENDED WEAK ISOSPIN MODEL

When the constituents of hadrons and their dynamics were not yet fully known, some patterns of baryon and meson resonances were explained by using strong isospin invariance. By analogy to this, it is expected that weak isospin symmetry can be used to reveal many properties of excited fermions without knowing their possible internal structure. From this point of view, the quantum numbers of the excited states can be determined without knowing the preon dynamics explicitly. We can determine the allowed weak isospin multiplets by adding the weak isospin values of the SM fermions and the gauge bosons (keeping in mind the angular momentum addition rule). Since SM fermions have $I_W = 0$ or $1/2$, and gauge bosons have $I_W = 0$ or 1; excited fermionic states with $I_W \leq 3/2$ are allowed. Since the weak hypercharge $Y = 0$ for all gauge fields, a given exotic multiplet couples via the gauge fields to an SM multiplet having the same Y value. Also, as we mentioned before, to ensure current conservation, the couplings has to be of the anomalous magnetic moment type. The effective Lagrangian used to calculate the decay modes and production cross sections is

$$\mathcal{L}_{eff} = g' B^\mu J_\mu^Y + g \overrightarrow{W^\mu} \cdot \overrightarrow{J_\mu} + g_s G^{\mu a} J_\mu^a \,. \quad (1)$$

In Eq. (1); $J_\mu^Y, \overrightarrow{J_\mu}$ and $J_\mu^a$are hypercharge, isovector and color currents; B^μ, $\overrightarrow{W^\mu}$ and $G^{\mu a}$ are $U(1)$, $SU(2)$ and $SU(3)$ gauge fields; g', g and g_s are coupling constants for these gauge filds, respectively. Quantum numbers of excited leptons and excited quarks are listed in Table 2 and Table 3.

Table 2. Quantum numbers of excited leptons.

I_W	Multiplet	Q	Y	Coupled to
0	$L_0 = L^-$	-1	-2	l_R through B^μ
1/2	$L_{1/2} = \begin{pmatrix} L^0 \\ L^- \end{pmatrix}$	0 -1	-1	$l_L = \begin{pmatrix} \nu_l \\ l^- \end{pmatrix}_L$ through W^μ and B^μ
1	$L_1 = \begin{pmatrix} L^0 \\ L^- \\ L^{--} \end{pmatrix}$	0 -1 -2	-2	l_R through W^μ
3/2	$L_{3/2} = \begin{pmatrix} L^+ \\ L^0 \\ L^- \\ L^{--} \end{pmatrix}$	1 0 -1 -2	-1	$l_L = \begin{pmatrix} \nu_1 \\ l^- \end{pmatrix}_L$ through W^μ

Lepton multiplets for $I_W = 0, 1/2, 1, 3/2$; their charges Q, hypercharges Y and the fields through which they couple to SM leptons.

Table 3. Quantum numbers of excited quarks.

I_W	Multiplet	Q	Y	Coupled to
0	i) $Q_0 = U$ ii) $Q_0 = D$	2/3 -1/3	4/3	u_R through B^μ and $G^{\mu a}$ d_R through B^μ and $G^{\mu a}$
1/2	$Q_{1/2} = \begin{pmatrix} U \\ D \end{pmatrix}$	2/3 -1/3	1/3	$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L$ through W^μ, B^μ and $G^{\mu a}$
1	i) $Q_1 = U_1 = \begin{pmatrix} U^+ \\ U \\ D \end{pmatrix}$ ii) $Q_1 = D_1 = \begin{pmatrix} U \\ D \\ D^- \end{pmatrix}$	5/3 2/3 -1/3 2/3 -1/3 -4/3	4/3 -2/3	u_R through W^μ d_R through W^μ
3/2	$Q_{3/2} = \begin{pmatrix} U^+ \\ U \\ D \\ D^- \end{pmatrix}$	5/3 2/3 -1/3 -4/3	1/3	$q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L$ through W^μ

Quark multiplets for $I_W = 0, 1/2, 1, 3/2$; their charges Q, hypercharges Y and the fields through which they couple to SM quarks.

Contributions to these transition currents come from certain weak isospin states. As can be seen from Eqs. (2a) and (2b), hypercharge current J_μ^Y receives contributions only from $I_W = 0$ and $1/2$ states.

$$J_\mu^Y(I_W = 0) = -\left(\frac{f_0'}{M_L}\right)\left(\overline{L_0}\sigma_{\mu\nu}q^\nu l_R + h.c.\right) + \left(\frac{2f_{0u}'}{3M_L}\right)\left(\overline{U}\sigma_{\mu\nu}q^\nu u_R + h.c.\right) - \left(\frac{f_{0d}'}{3M_L}\right)\left(\overline{D}\sigma_{\mu\nu}q^\nu d_R + h.c.\right) \quad (2a)$$

$$J_\mu^Y(I_W = 1/2) = -\left(\frac{f'}{2M_L}\right)\left(\overline{L_{1/2}}\sigma_{\mu\nu}q^\nu l_L + h.c.\right) + \left(\frac{f_q'}{6M_L}\right)\left(\overline{Q_{1/2}}\sigma_{\mu\nu}q^\nu q_L + h.c.\right) \quad (2b)$$

Isovector current $\overrightarrow{J_\mu}$ receives contributions only from the $I_W = 1/2$, 1 and $3/2$ states (Eqs. (3a), (3b) and (3c)).

$$\overrightarrow{J_\mu}(I_W = 1/2) = \left(\frac{f}{M_L}\right)\left(\overline{L_{1/2}}\sigma_{\mu\nu}q^\nu \frac{1}{2}\vec{\tau}\, l_L + h.c.\right) + \left(\frac{f_q}{M_L}\right)\left(\overline{Q_{1/2}}\sigma_{\mu\nu}q^\nu \frac{1}{2}\vec{\tau}\, q_L + h.c.\right) \quad (3a)$$

$$\overrightarrow{J_\mu}(I_W = 1) = \left(\frac{f_1}{M_L}\right)\left(\overline{L_1}\sigma_{\mu\nu}q^\nu\, l_R + h.c.\right) + \left(\frac{f_{1u}}{M_L}\right)\left(\overline{U_1}\sigma_{\mu\nu}q^\nu\, u_R + h.c.\right) + \left(\frac{f_{1d}}{M_L}\right)\left(\overline{D_1}\sigma_{\mu\nu}q^\nu\, d_R + h.c.\right) \quad (3b)$$

$$\overrightarrow{J_{\mu m}}(I_W = 3/2) = C\left(\frac{3}{2}, M \,\middle|\, 1, m; \frac{1}{2}, m'\right) \times \left[\left(\frac{f_3}{M_L}\right)\left(\left(\overline{L_{3/2}}\right)_M \sigma_{\mu\nu}q^\nu\, l_{Lm'} + h.c.\right) + \left(\frac{f_{3q}}{M_L}\right)\left(\left(\overline{Q_{3/2}}\right)_M \sigma_{\mu\nu}q^\nu\, q_{Lm'} + h.c.\right)\right] \quad (3c)$$

Color current J_μ^a receives contributions only from the $I_W = 0$ and $1/2$ states (Eqs. (4a) and (4b)).

$$J_\mu^a(I_W = 0) = \left(\frac{f_{su}}{M_L}\right)\left(\overline{U}\sigma_{\mu\nu}q^\nu \frac{1}{2}\lambda^a u_R + h.c.\right) + \left(\frac{f_{sd}}{M_L}\right)\left(\overline{D}\sigma_{\mu\nu}q^\nu \frac{1}{2}\lambda^a d_R + h.c.\right) \quad (4a)$$

$$J_\mu^a(I_W = 1/2) = \left(\frac{f_s}{2M_L}\right)\left(\overline{Q_{1/2}}\sigma_{\mu\nu}q^\nu \frac{1}{2}\lambda^a q_L + h.c.\right) \quad (4b)$$

In Eqs. (2-4) q^ν is the four-momentum of gauge filed, the various constants f, f', f_s etc. are dimensionless coupling constants, $\sigma_{\mu\nu}$ is the antisymmetric tensor with $\sigma_{\mu\nu} = \frac{i}{2}(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$ where γ_μ being the Dirac matrices, M_L is the mass of excited fermion. In Eq. (3c), C denotes the Clebsch-Gordon coefficients, in Eqs. (3a) and (4a-4b) $\vec{\tau}$ and λ^a are Pauli and Gell-Mann matrices, respectively. As can be seen from Table 2 and Table3, L^{--} in the lepton sector and U^+ and D^- in the quark sector have unusual electric charges and it is important to examine these excited fermions. By convention, L^{--} is called *"doubly charged lepton"*, and U^+ and D^- called *"exotic quarks"*.

PHENOMENOLOGICAL STUDIES

As explained in the previous section and given in the effective Lagrangian, when both nonstandard weak isospin states are considered (I_W=1 and $3/2$), the doubly charged leptons can couple to the SM leptons only through the W- boson field. The interaction Lagrangians describing the doubly charged lepton, SM lepton and a gauge boson vertex are given in Eq. (5) and Eq. (6) for the I_W=1 and I_W=$3/2$ values, respectively.

$$\mathcal{L}_{GM}^{(1)} = i\frac{gf_1}{\Lambda}\left(\bar{L}\sigma_{\mu\nu}\partial^\nu W^\mu \frac{1+\gamma_5}{2} l\right) + h.c. \qquad (5)$$

$$\mathcal{L}_{GM}^{(3/2)} = i\frac{gf_3}{\Lambda}\left(\bar{L}\sigma_{\mu\nu}\partial^\nu W^\mu \frac{1-\gamma_5}{2} l\right) + h.c. \qquad (6)$$

g is the $SU(2)$ coupling constant and it is equal to $g = \frac{g_e}{\sin\theta_W}$ where $g_e = \sqrt{4\pi\alpha}$. f_1 and f_3 are new coupling constants related to effective interactions of I_W =1 and I_W =3/2 multiplets, Λ is the compositeness scale, and L and l stand for doubly charged lepton and SM lepton, respectively.

The Lagrangians describing the interactions of exotic quarks with SM quarks and gauge boson are

$$\mathcal{L}_{GM}^{(1)} = \frac{gf_1}{\Lambda}\sum_{m=0,\pm1}\{[(\bar{U}_1)_m\,\sigma_{\mu\nu}u_R][(\bar{D}_1)_m\sigma_{\mu\nu}d_R]\}\partial^\nu (W^m)^\mu + h.c. \qquad (7)$$

$$\mathcal{L}_{GM}^{(3/2)} = \frac{gf_3}{\Lambda}\sum_{M,m,m'} C(\tfrac{3}{2}, M \,|\, 1, m; \tfrac{1}{2}, m') \times [\left(\bar{Q}_{3/2}\right)_M \sigma_{\mu\nu} q_{Lm'}]\partial^\nu (W^m)^\mu + h.c. \qquad (8)$$

The sum is taken over all possible weak isospin projection states (denoted by m, m' and M) in Eqs (7) and (8).

Phenomenological studies on doubly charged leptons predicted by the extended weak isospin model are quite rare in the literature. In the first paper in which the basics of the model are given, [32], the dominant decay modes and decay widths for excited leptons and quarks for all states with $I_W \leq 3/2$ are listed in detail. Also, the production of excited quarks with $I_W = 0, 1, 1/2$ and $3/2$ at $\bar{p}p$ colliders are discussed in [32].

The production of doubly charged antileptons ($Q = +2e$) at the LHC is considered in [33]. In the specified work, weak isospin multiplets $I_W = 1$ and $I_W = 3/2$ are taken into account. The production cross section at the LHC of $L^{++}(pp \rightarrow L^{++}l^{-})$ is calculated and the authors concentrate on the leptonic signature deriving from the cascade decays $L^{++} \rightarrow W^{+}l^{+} \rightarrow l^{+}l^{+}\nu_{l}$. Therefore, the final state in this process is $pp \rightarrow (l^{+}l^{+})\nu_{l}l^{-}$ and it is showed that the invariant mass distribution of the like-sign dilepton has a sharp end point corresponding to excited lepton mass M_L. In order to perform the needed numerical calculations of the production cross sections and kinematic distributions, the extendend weak isospin model is implemented in a parton level generator CalcHEP [34-35] and all the analytical results are compared with the output of CalcHEP sessions dealing with parton cross sections and decay widths. In the specified study, detector effects are also taken into account and the Pretty Good Simulator (PGS) program [36] is used. It is found that the LHC with $\sqrt{s}$=14 TeV can reach a sensitivity at 3-sigma (5-sigma) level up to M_L =1 TeV for the integrated luminosity values $L_{int} = 20$ fb^{-1} ($L_{int} = 60$ fb^{-1}).

However, production of doubly charged leptons at LHC via contact interactions is considered in [37] and it is found to dominate the production mechanism of the doubly charged leptons.

The production of doubly charged leptons and the corresponding signals, considering the electron-electron mode of the future linear colliders, is considered in [38]. In the specified work, the single production of first generation doubly charged leptons through the $e^{-}e^{-} \rightarrow E^{--}\nu_{e}$ process is taken into account and t and u channel interference is evaluated that has been neglected so far. The authors focus on a pure leptonic final state by considering the decay $E^{--} \rightarrow W^{-}e^{-} \rightarrow e^{-}\overline{\nu_{e}}e^{-}$, so the final state is $e^{-}e^{-} \rightarrow e^{-}e^{-}\overline{\nu_{e}}\nu_{e}$ which is experimentally translates into a like-sign dilepton and missing transverse energy signature. Better than the constraints obtained for the LHC, the mass limit for the linear collider with center-of-mass energy of 3 TeV is obtained as $M_L \approx 2.2$ TeV and the lower limit for the compositeness scale is obtained as $\Lambda > 25$ TeV. In the specified study, it is particularly emphasized that, apart from direct production, it would be interesting to investigate the indirect production of doubly charged leptons via the $e^+e^- \rightarrow W^+W^-$ process at linear colliders.

Direct production of doubly charged leptons by considering another mode of electron-positron linear colliders, the electron-photon mode, is discussed in [39]. Production cross section of the $e^-\gamma \rightarrow L^{--}W^+$ process is discussed and the analyses for hadronic, semi leptonic and pure leptonic channels based on the full simulation of the silicon detector are carried out. It has been found that the hadronic channel could provide the most probable detectable signature.

Single production of doubly charged leptons at the future ep collider Large Hadron electron Collider (LHeC) is studied in [40]. The doubly charged leptons can be singly produced through the process $e^-p \rightarrow L^{--}j$ and this process involves the partonic processes $e^-q \rightarrow L^{--}q'$ and $e^-\bar{q} \rightarrow L^{--}\bar{q}'$, where j denotes the jets and q and q' are the quarks with different flavor. In the specified study, gauge and contact interactions or a combination of both are considered. The leading order cross sections are calculated by using the high energy simmulation program MadGraph5 [41]. Considering the leptonic (hadronic) decay modes of the W boson, signals and backgrounds through the processes $e^-p \rightarrow L^{--}j \rightarrow e^-W^-\,j \rightarrow e^-l^-\bar{\nu}_l j\ (e^-jjj)$ are discussed. It is found that for a discovery in the leptonic channel for $M_L > 920\ (1440)$ GeV at $\sqrt{s} = 1.3\ (1.98)$ TeV, the needed luminosity detecting the signal is larger than 10^4 fb^{-1}.

Taking into account the lepton flavor conservation, single production of doubly charged leptons carrying muonic lepton number studied in [42]. Considering three different μp colliders, cuts best suited for the discovery are defined dealing with the $\mu^-q(\bar{q}') \rightarrow L^{--}\ q'(\bar{q}) \rightarrow W^-\mu^-q'(\bar{q})$ subprocess. By an analysis at the partonic level, a mass constraint of 4.7 TeV is imposed for the second generation doubly charged leptons in a μp collider with a center-of-mass energy of 12.2 TeV.

An investigation for the search potential of the doubly charged leptons at the Future Circular Collider (FCC) based energy-frontier electron-proton colliders with the center-of- mass energies of $\sqrt{s} = 3.46, 10,$ and 31.6 TeV is discussed in [43]. The authors deal with the process $e^-p \longrightarrow L^{--}X \longrightarrow e^-W^-X$, calculate the production cross sections, and give the normalized transverse momentum and pseudorapidity distributions of final-state electron to obtain the kinematical cuts for the discovery. By implying the discovery cuts on the final-state electron and also impose an invariant mass cut on the eW system, by choosing hadronic decay mode of W boson ($W \longrightarrow jj$), the obtained mass limit of doubly charged lepton for the exotic multiplet I_W = 1 (I_W = $3/2$) is 5.46 (8.47) TeV at $\sqrt{s} = 10$ TeV with $L_{int} = 10$ fb^{-1}.

A similar study is carried out by using two other future *ep* collider that have different parameters in [44]. The contour graphics at $\Lambda - M_L$ parameter space are plotted and it is deduced that the observation (3σ) mass limits for the Λ as Λ ~ 2.6 (4) TeV for M_L=1.75 (3.30) TeV at $\sqrt{s}$= 8.44 (26.68) TeV.

The first and the unique study for the production at the CERN LHC of new exotic quark states of electrical charge $Q = (5/3)e$ and $-(4/3)e$ which appear in composite models of quarks and leptons when considering higher isospin multiplets I_W = 1 and I_W = $3/2$ is presented in [45]. Magnetic type gauge interactions are implemented in the CalcHEP generator; signal and relevant SM background (Wjj) fast simulation of the detector reconstruction is performed based on the Delphes software [46]. It is found that for I_W = 1 $(3/2)$, for the integrated luminosity equal to L_{int} = 30 fb^{-1} at a 3-sigma level mass reach respectively up to $M_L \approx$ 2230 (2930) GeV.

In a very recent study [47], the effects of excited fermions in the extendend weak isospin models with isospin triplets (I_W = 1) on the muon's magnetic moment $(g - 2)_\mu$ at the one-loop level are investigated.

In an ongoing study, MadGraph5 model files have been prepared for excited leptons with weak isospin values (1 and $3/2$) considered in the extended weak isospin model [48]. To check the model files, the analytical calculation for the decay width of the doubly charged lepton is compared with the outputs of CalcHEP and MadGraph5 and the results are found to be in good agreement (as seen in Fig. 1). Therefore, by relying on model files, phenomenological studies of doubly charged leptons and exotic quarks can be carried out for the future high-energy particle colliders, taking into account detector effects.

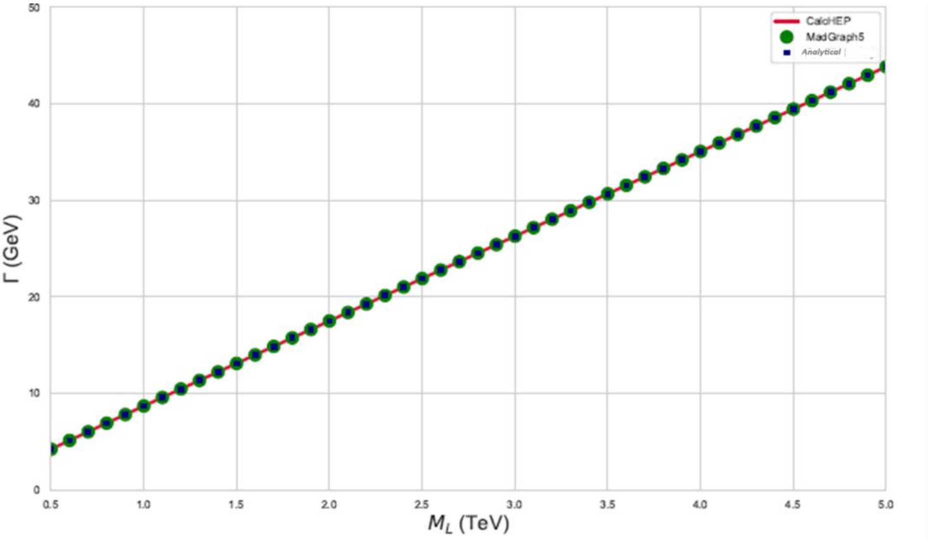

Figure 1. Comparison of analytical calculation and simulation program outputs.

CONCLUSION

The discovery of fermions with an exotic electric charge, which we encounter in the extended weak isospin model, would be significant evidence for the fermion compositeness. In this study, firstly the basic information about the theory of the extended weak isospin model is given. Then, a review of the phenomenological studies carried out up to date on the study of fermions with $I_W = 1$ and $I_W = 3/2$ in the next generation colliders is given.

Other possible phenomenological studies can be summarized as follows:

1) Indirect search for doubly charged leptons in future lepton colliders (both for e^-e^+ and $\mu^-\mu^+$ colliders).

2) Investigation of doubly charged leptons and exotic quarks via gauge and contact interactions in future hadron colliders.

3) Investigation of second generation doubly charged leptons in muon colliders (including muon-photon options).

4) Determining the effects of excited fermions with isospin quadruplets ($I_W = 3/2$) on the muon anomalous magnetic moment.

By conducting the studies mentioned above, an important gap in the literature could be filled and the obtained results could provide important inputs for future particle physics experiments. The possible discovery of fermions with weak isospin values of $I_W = 1$ and $I_W = 3/2$ at the colliders planned to be built after the LHC will provide important clues to answer many questions that the SM cannot answer today.

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CHAPTER 2

GREEN EXTRACTION METHODS

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INTRODUCTION

In recent years, with the development of healthy nutrition awareness, consumers' expectations of foods are changing, and interest in bioactive components is increasing due to their positive effects on health and to fully meet nutrient needs. For the body to fulfill its functions, the risks of diseases that may be encountered in the future are minimized with an adequate and balanced intake of the necessary nutrients and bioactive components contained in foods. It is known that bioactive components have protective properties against oxidative stress caused by free radicals and exhibit antioxidant activity under in vitro and in vivo conditions. Studies show that bioactive components have positive effects on many diseases such as some types of cancer, cardiovascular diseases, inflammation, neurological diseases, obesity, and osteoporosis. Separating bioactive components from inert or inactive parts of animal or plant tissues using selective solvents is called 'extraction' (Handa et al., 2008).

Extraction is used in the recovery of valuable food components (such as phenolic compounds), product extraction (such as sugar, fat and protein), isolation of food components (such as aroma substances), and removal of undesirable compounds in food (such as alkaloids, cholesterol) (Kırıcı and Vayısoğlu 2021). The extraction process is one of the separation methods used in the sample preparation process for removing and enriching target compounds from the sample matrix (Pawliszyn, 2003).

The bioactive components obtained in extraction should be obtained without loss and degradation and additional purification (Demir et al., 2015). An ideal extraction method should be simple, inexpensive, fast and environmentally friendly as well as provide high yields of the desired component (Chemat et al., 2012; Rombaut et al., 2014).

With changing living conditions, significant changes in demographics and an increasingly widespread global food market, food supply and diversity have increased considerably. To keep pace with the diversity of food in the global market, the food supply chain and food safety management systems need to be continuously adapted and improved (Gorris, 2005). Current food systems lead to the depletion of natural resources, ecosystem degradation, climate change, poverty, hunger, malnutrition, agricultural land degradation, water scarcity, social inequalities and biodiversity loss (El Bilali et al., 2019).

The negative impacts of the food industry on nature, which has become a global problem, have led to the initiation of green technology movements with the efforts of non-governmental organizations and governments. The food industry needs to meet green technology alternatives in terms of harmful substances, energy consumption and by-product recycling during food production processes (María et al., 2019). Green technologies aim to improve the industrial use of environmentally friendly technologies for sustainable food production and processing (Boye and Arcand, 2013).

After the definition of the green chemistry approach in the early 1990s and the publication of 12 green chemistry principles by Anastas and Warner (Waldebäck 2005; Chemat et al., 2012; Rombaout et al., 2014), green extraction was defined (Waldebäck 2005). According to this definition, green extraction is defined as an extraction method based on the discovery and design of extraction processes that will reduce the energy consumption of extraction processes, allow the use of alternative solvents and renewable natural products, and obtain reliable and high-quality extracts/products (Chemat et al., 2012). With the definition of green extraction, the food and nutraceutical industries want to meet the requirements of green technology while achieving safe and high-quality extracts/products in the extraction processes applied (Tiwari 2015).

Today, the most commonly used traditional extraction methods for the extraction of bioactive compounds are heat reflux, boiling, maceration, and infusion. In most experiments in traditional methods, water and ethanol are used as solvents, as well as other environmentally harmful solvents such as methanol, acetone, acetonitrile, ethyl acetate, dichloromethane, hexane, and petroleum ether. In these methods, disadvantages such as the application of temperatures above 100°C and the long duration of the extraction process make traditional methods disadvantageous compared to non-traditional methods. (Suan, 2013; Luna et al, 2020).

Non-traditional extraction methods have become more widely used due to their global advantages such as non-thermal effects and prevention of degradation of thermolable compounds (Ju and Howard 2003; Zhang et al., 2011) reduction in the amount of solvent, reduction in extraction time, (Jun, 2006; Luengo et al., 2013) reduction in energy consumption, higher yield and selectivity in compounds of interest, automatic and reasonably reproducible processes, and environmental friendliness (Briones-Labarca et al., 2019). Non-traditional extraction methods can be classified as general Mechanical Force

Methods, Electromagnetic Forces, Electrical Forces, and Enzymatic extraction methods for certain biocatalytic reactions Luna et al, 2020).

1. Mechanical Force Methods

1.1. Ultrasound Extraction (UE)

Ultrasound is a method in which sound waves produce energy by vibrating 20,000 or more times per second. This technology, which is widely used in the food industry, is generally applied at frequencies between 20 kHz and 1 MHz. This frequency range has been optimized to obtain effective results in various food processing applications. The use of ultrasound in the food industry allows more effective and faster results by reducing the amount of solvent in mixing, emulsification, extraction and other processes. Sound waves with a frequency above 20 kHz are called ultrasound waves (Ponmurugan et al., 2017).

The ultrasound-assisted extraction method is an extraction method that stands out with its simple application, low cost and high efficiency. Ultrasonic waves increase efficiency by increasing the reaction rate in solid-liquid extraction. This feature makes it a preferred method, especially for the extraction of heat-sensitive substances. Ultrasound-assisted extraction is a technique used to obtain effective and fast results in various industrial applications (Ponmurugan et al., 2017).

The 'green chemistry' technology, which is a method that enables the extraction of valuable components with cavitation bubbles caused by ultrasound waves, enables the recovery of desired bioactive components with the least degradation by increasing the mass transfer of ultrasound (Ponmurugan et al., 2017). The collapse of cavitation bubbles in regions close to the surface of the plant sample causes an increase in temperature and pressure. As a result of these increases, plant cell wall deteriorations occur and plant components pass into the solvent medium. This process represents an effective mechanism for the extraction of bioactive components from plant cells by ultrasound-assisted extraction. It is a non-thermal, simple, efficient and cheap technique that uses less solvent, is performed in a shorter time and with less energy compared to traditional methods. Solvent consumption is reduced with ultrasound support, the processing time is shortened, reproducibility is facilitated and the product obtained is of higher purity. Ultrasound-assisted extraction can consist of an ultrasonic bath or probe system. An ultrasonic bath is a tank containing an ultrasonic transducer and also includes a temperature control device operating at a fixed frequency (Figure 1). The probe system is more efficient than the ultrasonic bath, but the ultrasonic bath is preferred more because it is easy to use and cheap. It works in the frequency range of 20-100 kHz. In food applications, ultrasound frequencies between 20 kHz and 1 mHz are generally used. Wavelengths above 1 mHz are used for imaging purposes in medicine (Yang et al., 2011).

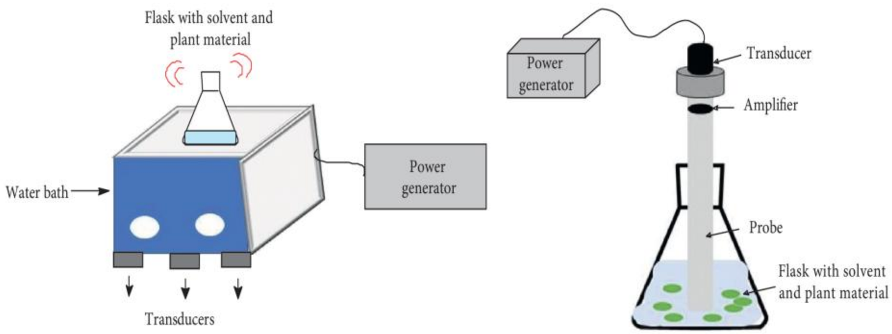

Figure 1. Scheme of ultrasound equipment: bath system and probe system (Rodríguez et al., 2020).

Ultrasound has two main effects: thermal effect and mechanical effect. The thermal effect occurs in particular when the heat caused by the ultrasonic waves is absorbed by the sample. It is known that the increase in extraction obtained using ultrasonic power is due to the effects of acoustic cavitations produced in the solvent by the passage of an ultrasonic wave. It is stated to have a mechanical effect on the increase of the contact surface area between the solid and liquid phases, allowing the solvent to contact the sample more (Feng and Yang, 2011).

1.2. Pressurized Liquid Extraction (PLE)

Pressurized liquid extraction, also known as accelerated solvent extraction, was introduced in 1995. It is a process that combines high pressures and temperatures with organic solvents above its boiling point. PLE is a method that works with subcritical liquids solvents usually at pressures ranging from 4 to 12MPa and uses from moderate to high temperatures, ranging from 50 to 300°C. (Richter et al., 1996; Luna et al, 2020).

It is a fairly new technique for extraction. It is also called accelerated solvent extraction. It uses equipment that allows higher temperatures to be used for conventional solvents by keeping the sample in a sealed high-pressure environment. The elevated pressure allows the solvent to exist in a liquid state at higher temperatures. One of the critical factors affecting yield and selectivity in PLE is the temperature applied during extraction. The use of high temperatures increases extraction efficiency by helping to disrupt analytic-sample matrix interactions such as van der Waals forces, hydrogen bonding and dipole attraction10. The use of thermal energy helps to overcome cohesion forces between similar molecules and adhesion forces between different molecules. This reduces the activation energy required for the desorption process. The elevated temperature reduces the surface tension of the solvent, solute and matrix. Therefore, the wetting of the sample increases. The decrease in solvent surface tension allows the solvent cavity to form more easily. This allows the analytes to dissolve faster in the solvent. Increased temperature reduces the viscosity of the liquid solvent and facilitates the penetration of matrix particles. Temperature helps break down strong analyte and matrix interactions and increases diffusion rates that shorten the equilibrium time. This allows for faster extractions, especially in diffusion-controlled samples (Mockel et al., 1987). The key feature of PLE is that it uses high-diffusion fluids, which increases the speed of the extraction process while significantly reducing the amount of solvent required (Moreno et al., 2007). PLE aims to improve liquid extraction using high temperature and pressure. High temperature and pressure increase the solvent's ability to penetrate into the sample matrix. Usually, extraction is performed at a temperature above the atmospheric boiling point of the solvent. The diffusivity and solubility of the analyses increase with increasing temperature. This makes the extraction faster and more efficient (Richter et al., 1996; Lundstedt et al., 2000). The main advantage of the pressure applied during extraction is that the solvent remains liquid even if the temperature rises above the boiling point. High pressure during extraction controls problems with air bubbles in the matrix that prevent the solvent from reaching the analysis (Figure 2). These conditions increase the solubility of the analyses and the kinetics of desorption from the matrix (Rostagno et al., 2009).

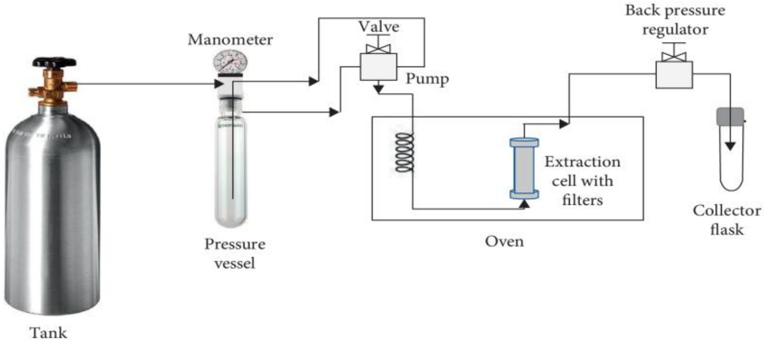

Figure 2. Scheme of pressurized liquid extraction equipment (Rodríguez et al., 2020).

1.3. High Hydrostatic Pressure (HHP)

The first study for high hydrostatic pressure was presented in 1883 and it was found that HHP could have effects on organisms related to deep-sea ecosystems (Stal and Cretoiu, 2016). Until the 1980s, the system developed and was found to be an advantageous alternative to thermal food processes. Today, the HHP system finds various applications in the food industry for various purposes such as enzyme inactivation, reduction of microbial load, spoilage control, foaming of products, and improvement of product properties for quality (Balasubramaniam et al., 2015). HHP application in the food industry has many advantages besides high installation costs. Since the system is considered a new non-thermal technology, its main advantage can be overcoming or minimizing the negative effects of thermal processes. Applying high pressure instead of high temperatures or as a pretreatment helps to ensure food safety without significant changes in the physico-chemical and quality properties of the products (Huang et al., 2017).

High pressure creates an effective physical stress to break the cell wall even for pressure-resistant cells and causes irreversible cell damage (Alpas et al., 2003). Cell structure is fragile so high pressure produces a destructive effect on the cell membrane, denatures the protein structure of the cell and causes cell deformation (Figure 3) (Guo et al., 2012).

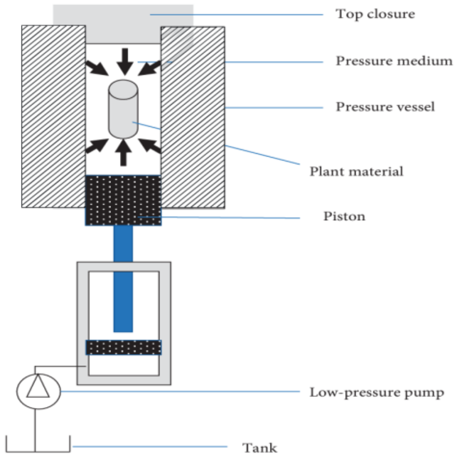

Figure 3. Scheme of high hydrostatic pressure equipment (Rodríguez et al., 2020).

The working principle of the HHP system is to apply the same pressure to all points of the sample in all directions at the same time and for the same period with the help of pressure transmission of the pressurizing medium, which is a liquid. This principle makes the process uniform. In terms of applications in the food industry, the pressurizing fluid is mostly water; however, in pilot-scale applications, glycol or glycol water and different oils can be used. The pressurizing fluid is selected considering the effect of pressure on its viscosity, compressibility at different temperatures and corrosion properties (Balasubramanian, 2003). The parameters of the HHP system are pressure, temperature and time. A wide range of pressures and temperatures, 100-1000 MPa and -20 - 100 °C, respectively, can be applied. The pressurization time can be regulated from seconds to minutes over 20 minutes (Yaldagard et al., 2008). The equipment consists of many parts that vary in size and capacity depending on the scale of the process, the product to be pressurized and the required process conditions (Balasubramaniam et al., 2015).

1.4. Supercritical Fluid Extraction (SFE)

In SFE, the extraction fluid is in a supercritical state. A supercritical fluid is defined as an element, substance or mixture heated above its critical temperature and pressurized above its critical pressure. A supercritical fluid exists in a single phase (neither gas nor liquid) and cannot be liquefied or vaporized by increasing pressure or temperature. A supercritical fluid therefore represents an intermediate form of matter between a gas and a liquid. They have high density and solvency like that of a liquid, low viscosity like that of a gas, zero surface tension and a high diffusion rate for analyses. Due to their higher diffusion coefficients and low viscosity, supercritical fluids are well-suited to penetrate solid porous materials. They have fast reaction kinetics, as their dissolving and spreading power is greater than that of liquids (Mira et al., 1999; Zougagh et al., 2004).

Extraction with supercritical fluid is one of the newer extraction techniques that can offer an excellent extraction yield (Vinatoru, 2001; Romanik et al., 2007). A supercritical fluid extraction can be summarized in two principal processes: (1) extraction of analytes by using the supercritical fluids, and (2) separation of analytes from them (Figure 4). Because of the low viscosity and the high diffusion coefficient of supercritical fluids, these latter can easily penetrate sample particles and drain with them the soluble analytes (Romanik et al., 2007; Benchikh et al., 2023).

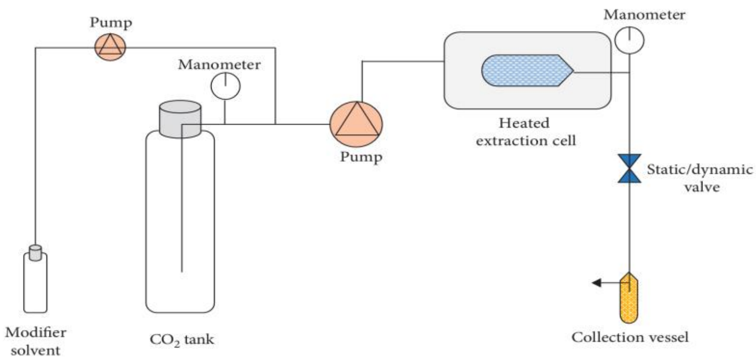

Figure 4. Scheme of supercritical fluid equipment (Rodríguez et al., 2020).

Traditional extraction techniques are not always preferred in obtaining extracts due to the toxicity of many traditional organic solvents, which are considered to have an acceptable quality/cost ratio. In addition, many of the solvents used also exhibit poor selectivity. Therefore, primary products require the search for important new solvents that dominate the costs associated with obtaining the final product. $ScCO_2$ extraction has been developed for this purpose. In $ScCO_2$ extraction, solvent residues are at a minimum level and high-quality extracts can be obtained. This method is usually applied under high pressure, from 100 to 500 bar. However, product acquisition can result in high costs. Scientists are engaged in intensive efforts and research to determine new extraction methods that are quality extracts, affordable and widely applicable (Shilpi et al, 2013).

2. Electromagnetic Force Methods

2.1. Microwave-Assisted Extraction (MAE)

Microwaves are called electromagnetic fields with a frequency range between 300 MHz and 300 GHz. In these fields, the electric field and the magnetic field are perpendicular and have two oscillations. Microwave systems can directly heat polar substances. Electromagnetic energy creates pressure with the ion flow in the environment and thus heat is generated. The current difference between conventional heating and heating with microwave energy is seen in Figure 5. Ions shift to different orbits and create collisions between molecules. The extraction technique used selectively to obtain organic and organometallic compounds with low degradation is Microwave-assisted extraction. The low use of organic solvent and energy calls this extraction method the green extraction method (Azmir et al. 2013).

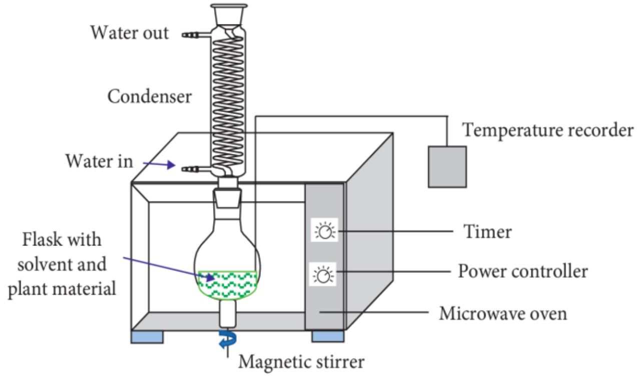

Figure 5. Scheme of general MWAE equipment (Rodríguez et al., 2020).

The microwave-assisted extraction method is more advanced than the conventional extraction method. The reason for this is that the matrix is heated internally and externally without thermal degradation. Functional compounds can be easily extracted without degradation in an efficient and preservable way.

Microwave extraction is based on the principle of rapid heating and evaporation of moisture inside cells by the microwave effect. With this pressure effect, the cell wall is broken down and mixed with the solvent. This extraction method provides high efficiency despite being effective in a very short time. More than 90% of polyphenols in plant seeds can be extracted in a few minutes using the microwave-assisted extraction method.

Basically, two types of MAE systems can be used: closed vessel system (under controlled temperature and pressure) and open vessel system (at atmospheric temperature). (Figure 5) (Camel, 2000). In a closed vessel system, cells are irradiated simultaneously, while in the open system, the vessels are irradiated sequentially. In open vessels, the temperature is limited by the boiling point of the solvent at atmospheric pressure, whereas in closed vessels the temperature can be increased by the applied pressure. The closed vessel system seems to be most suitable in the case of volatile compounds. However, in closed vessels, it is necessary to wait for the temperature to drop after extraction before opening the vessel. This increases the extraction time (Renoe, 1994).

2.2. Ohmic Heated Extraction

Ohmic heating is named after Ohm's law, which shows the relationship between current, voltage and resistance (Sastry and Barach, 2000). In the literature, it is also known as Joule heating, electro-conductive heating, electrical resistance heating, direct electrical resistance heating or electro-heating. Ohmic heating is an electro-heating technique based on the passage of electric current through food material. This system is particularly suitable for semi-solid food or food with particles (Goullieux, 2014). Heat is generated inside the food and the amount of heat generated is directly related to the voltage change and electrical conductivity. A schematic representation of the ohmic heating setup is given in Figure 6 (Sastry, 2004). As seen in Figure 6, AC (alternating current) voltage is applied to the electrodes at both ends of the system. The heating rate varies directly proportional to the square of the electric field strength and the electrical conductivity of the sample. The electric field strength can be varied by adjusting the spacing between the electrodes or the applied voltage. Furthermore, ohmic heating performance depends on the electrical conductivity of the product and the ambient temperature (Richardson 2001).

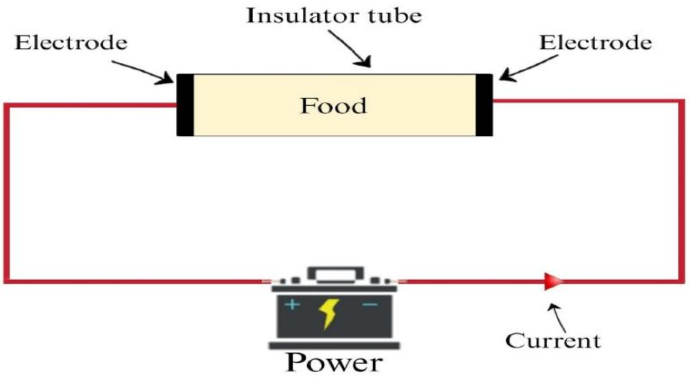

Figure 6. Scheme of Ohmic Heated System (Sastry, 2004).

If the product contains more than one phase, such as a liquid and a solid, the electrical conductivity of all phases must be taken into account. Electrical conductivity increases with increasing temperature. Therefore, it is known that 17 ohmic heating becomes more effective as the temperature increases. The difference in electrical resistance and temperatures between the two phases can make the heating characteristics of the system very complicated. Electrical conductivity can be affected by the ionic content of the material. Therefore, to obtain effective ohmic heating, it is possible to adjust the electrical conductivity of the material (for both liquid and solid phases) by the concentration of ions (e.g. salts) (Richardson 2001).

3. Electrical Force Methods

3.1. Pulsed Electric Field Extraction

Pulsed Electrical Field technology; It is a non-thermal technology that inactivates pathogenic microorganisms or is effective in reducing this load while preserving the taste, aroma and nutritional values of foods and is an alternative to traditional methods (El Darra et al., 2013). The PEF method is a system generally applied to fluid foods and is the forcing of high-intensity electric current through the food placed between two conductive electrodes and through the non-conductive tube. In this way, microorganisms are inactivated by giving electricity with a high intensity for very short periods (Boussetta, 2014). The mechanism of action of this method is based on electroporation and electrofusion. Since the pores of the cell expand or new pores are formed with electroporation, the cell cannot perform its function. In electrofusion, the cell membrane is mechanically destroyed depending on the charge distribution due to the high-intensity electric field.

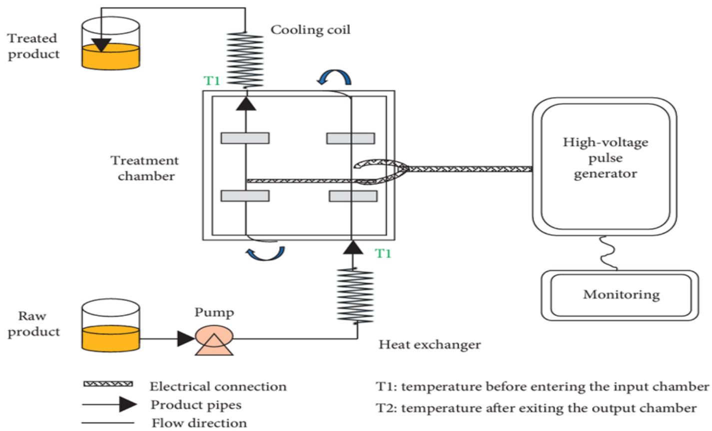

Figure 7. General scheme of a PEF equipment process (Rodríguez et al., 2020).

4. Enzymatic Reaction Systems

4.1. Enzyme-Assisted Extraction

Enzyme-assisted extraction (EAE) is a method based on the biocatalytic activity of diverse enzymes. The basic principle of EAE is the breaking of the cell wall of the plant by the action of one or various enzymes. Enzymes catalyze the hydrolysis of cell walls, releasing intracellular components (Nadar et al., 2018). An enzymes have an active site, which is an area where the substrate is linked to be catalyzed. e substrate is a molecule on which the enzyme acts. In this case, the substrates are found in the plant cell walls, which are composed of a series of polysaccharide complexes such as cellulose, hemicellulose, pectin, lignin, and some proteins. All these components confer to the cells' stability and resistance to the extraction of the bioactive compounds from the intracellular components. Generally, the substrate binds to the enzyme by coupling to an active site, causing a conformational change in its structure and a deep interaction with the substrate (cell wall). It leads to the breaking of the bonds of the cell wall and the release of its bioactive components. Therefore, the EAE process uses a wide range of carbohydrate hydrolyzing enzymes and may be either a single or a preparation of several enzymes. Enzymes such as pectinases, cellulases, and hemicelluloses hydrolyze the components of the cell wall, increasing the permeability and the extraction yield of specific compounds such as oils, polyphenols, polysaccharides, and pigments, among other medicinal compounds (Sowbhagya and Chitra, 2010; Puri et al., 2012; Nadar et al., 2018).

Enzymes such as xylanase, protease, amylase, papain, and hemicellulose have been employed in different EAE processes. There are several types of enzymes, which are classified as hydrolyzing, oxidation-reduction, group transfer, isomerizing, and carboxylation enzymes. Each of these enzymes acts on a specific substrate, depending on its catalytic reaction characteristics (Gligor et al., 2019). Generally, the intracellular biomolecules present in plant materials are found as insoluble substances or soluble conjugated forms (glycosides). For example, phenolic compounds are linked to the cell walls by hydrophobic interactions and hydrogen bonds. Some phenolic acids form ether bonds with the lignin through the hydroxyl groups present in the phenolic aromatic ring, and other acids form ester bonds with the carbohydrates and proteins of the cell wall by carboxylic groups. Some polyphenols are present as glycosides; these are polyphenols covalently linked to glucose segments. In the case of flavonoids, these are bound by covalent bonds with glucose sections through the OH (O-glucose) groups or carbon-carbon (C-glucose) bonds. Enzyme β-glucosidase can break glycoside bonds β-1,4. In addition to β-glucosidase, pectinases also hydrolyze the cellulose, hemicellulose, and pectin solubilizing cell wall components and accelerate the release of intracellular biomolecules (Nadar et al., 2018).

Conclusion

In selecting the technique to extract a desired compound from a plant; all parameters such as extraction efficiency and reproducibility, ease of the applied procedure, duration, cost and safety should be considered. On the other hand, the increasing economic value of bioactive compounds and functional foods enriched with these compounds will enable the development of more advanced extraction methods.

Thanks to the 'green extraction techniques', which are supported by the restrictions and regulations brought by national and international organizations within the framework of environmental regulations and are developed day by day; new alternative technologies that use more reliable chemicals with less energy consumption, cost and time will be developed and can be used in many different areas besides the food sector.

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CHAPTER 3

THE MUON COLLIDER AND SOME OF ITS APPLICATIONS ON NEW PHYSICS

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INTRODUCTION

A collider is a type of particle accelerator in which two particle beams are brought together to collide at high energies. There are various colliders such as the Large Hadron Collider (LHC), the Super Proton Synchrotron (SPS), Fermilab's Tevatron, the Large Electron-Positron Collider (LEP) and the Electron-Ion Collider (EIC). All particle accelerators developed to study and detect the fundamental particles and forces that made the universe. Their capabilities, their design, and the types of experiments they can perform are all very different.

There are a number of questions that need to be answered. Is the Higss boson an elementary particle or a composite particle? Why is electroweak symmetry broken and what sets the scale? Is the Higgs boson or the electroweak sector connected with dark matter? And much more. The next collider should deepen our understanding of such questions mentioned above, and provide broad and varied opportunities for exploration to enable radically unexpected discoveries.

Muon colliders were proposed firstly by F. Tikhonin and G. Budker at the end of the 1960s [1] and conceptually explained later by several scientists and collaborations (see a comprehensive list of references in Refs. [2-7]). The future muon collider is a particle accelerator concept which is designed to explore fundamental questions of particle physics. Over existing electron-positron and hadron colliders, muon collider offering unique advantages. It would collide beams of muons to probe the fundamental structure of matter at higher energies and precision. It has scientific impact on the field due to the potential for discoveries and complementary to other future colliders.

A muon collider could be a sustainable, innovative device for an ambitious leap forward in fundamental physics research. It is a long-term project, but with a tight schedule and a narrow window of opportunity. The work initiated must be continued over the next decade, encouraged by a positive recommendation from the US Particle Physics Prioritisation Panel (P5) in 2023 and the next update of the European Strategy for Particle Physics in 2026-27. By then, progress should be made on the prospects for developing, building and operating a muon collider, and for interpreting, recording and using the results of its collisions to advance physics. These are exciting challenges for accelerator physics, both theoretical and experimental.

Muon

Carl D. Anderson and Seth Neddermeyer discovered muons in 1936 while studying cosmic radiation. A muon (μ) is a subatomic particle belong to the lepton family, similar to an electron but with a much greater mass. The values of the muon and electron masses are ($m_\mu = 105.66\,\mathrm{MeV/c^2}$) and ($m_e = 0.511\,\mathrm{MeV/c^2}$) respectively. So muon mass is about $m_\mu/m_e = 207$ times the mass of an electron. It has electric charge -1 same as an electron and spin $1/2$. Muons are unstable with a mean lifetime of about 2.2 microseconds. They typically decay into electrons, muon neutrinos, and electron antineutrinos. Muons produced in the upper atomosphere when cosmic rays (high-energy particles from space) intract with atoms and due to their higher mass, they can penetrate materials more effectively. These collisions produce a cascade of particles, including muons.

Comparision of LHC with MC

Large Hadron Collider (LHC) collides protons. Protons are composite particles made of quarks and gluons. In the operation LHC collides protons to produces a wide range of particles, including Higgs bosons. This results in complex interactions and a wide variety of possible outcomes. Due to complex proton collissions, LHC experiences significant background noise, in the result it challanging to to identify rare events. LHC currently the world's most powerful collider, it reaches energies of up to 13 TeV in pp (proton-proton) collisions. However, the protons lose energy to synchrotron radiation. It requires large circumference about 27km. Including the Higgs bosons, LHC has made significant discoveries, but due to its high-energy noise and complexity it has limitations in searching certain rare processes. LHC is established technology.

Future muon collider (FMC) collides muons, which muons are also elementary particle like electron. In the operation FMC collides muons at very high energies. FMC expected to have more cleaner collisions then proton colliders. Potentially reach higher effective energies in a smaller space due to the heavier mass of muons, make them suitable for exploring high-energy physics while lose less energy through synchrotron radiation. It requires much smallr size for same energy. By probing rare phenomena FMC have the potential for discoveries with high energy and precision, revealing new physics beyond the Standard Model (BSM). It is potentially cheaper for same energies. FMC technology is still in development.

Physics Goals of Muon Collider

1. MC will probe the precision measurements of Higgs boson mass, Higgs boson's couplings to other particles and other properties.
2. Muon Colliders can search for supersymmetric particles, it will be potential candidates for the dark matter of the universe.
3. MC is advanced accelerator technologies which will develop the computing and data analysis techniques.
4. It will develop beyond standard model physics via the search for new particles at multi-TeV scale.

Advantages and challanges of MC

Constructing and operating a muon collider with usable luminosity requires significant technical challenges associated with the acceleration, production, cooling, capture, and storage of muons in large quantities. Reference [2,8] provide comprehensive overviews of the significant progress achieved in explaining and developing the technologies needed for such high luminosity energy frontier muon colliders. Let me write the summary of advantages and challenges of muon colliders in the list as follows:

1. Future muon colliders are more efficient acceleration to very high energies till multi-TeV range (~ 100TeV).
2. Future muon collider higher energy efficiency allows for circular colliders with ralatively smaller circumference than electron colliders of equivalent energy.
3. Muons mass, being 207 times heavier than electrons mass, minimizing energy loss through synchrotron radiation.
4. Future muon colliders have more precision due to clean point-like collisions, making it easier to identify rare events.
5. Significant technological challenges in the production and acceleration of intense muon beams. The production of a high quality muon beam is required to achieve the desired luminosities. Optimization and improved integration are required to achieve the performance goal while maintaining low power consumption and cost.

6. Muons have a shorter lifetime than protons. This limits the time available for collisions.

Muon Collider Concept

A long time ago initial ideas for muon colliders were proposed [9-13]. The Muon Accelerator Program (MAP) in the USA was the culmination of subsequent studies [14-17]. The MAP conceptual scheme for the muon collider facility is shown in Fig. 1. This describes the physical principles that motivate the current baseline design and outlines promising avenues that may lead to improved performance or efficiency.

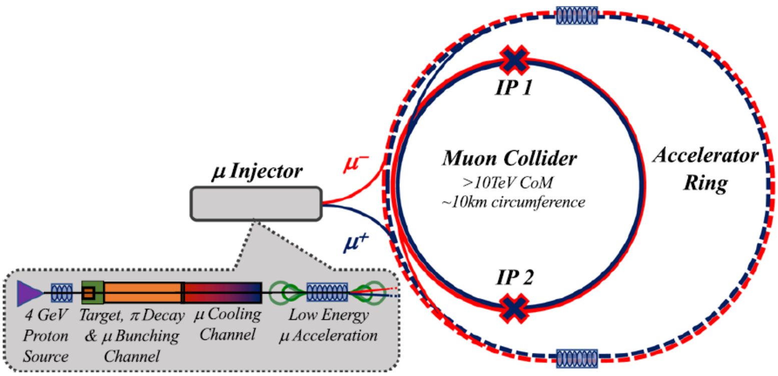

Fig. 1: A conceptual diagram of a muon collider showing the main stages.

Taken from Ref. Accettura, Carlotta, et al. "Towards a muon collider." *The European Physical Journal C* 83.9 (2023): 1-110. https://doi.org/10.1140/epjc/s10052-023-11889-x

The proton complex produces a short, high-energy intensity proton pulse that directs them to a target and produces pions. Pions decay into muons in a decay channel and collects the muons from their decay into the muon bunching and phase rotator system to form a muon intense beam. Due to muons' short lifetime, multiple cooling stages then reduce the longitudinal and transverse emittance of the beam using a sequence of absorbers and radiofrequency cavities in a high magnetic field. A system of linear accelerators and two recirculating linear accelerators accelerate the beams up to 60 GeV [18]. They are followed by one or more rings to accelerate them to higher energies, for instance one to 300 GeV and one to 1.5 TeV, in the case of a 3 TeV center of mass energy muon collider [18]. In the 10 TeV collider an additional ring from 1.5 TeV to 5 TeV follows. In the result, the beams are injected at full energy into the collider ring. They will circulate to produce luminosity until they are decayed. Alternatively, if the muon beam current is strongly reduced by decay, they can be extracted. There are wide scopes for the optimization of the exact energy levels of the accelerator system, taking also into account the possible use of the intermediate-energy muon beams for muon colliders of lower center of mass energy.

The Muon Accelerator Programme (MAP) has developed a concept for the muon collider, shown in Fig. 1. This developed concept serves as a starting point for the baseline concept and as a seed for the preliminary parameters in the design studies initiated by the International Muon Collider Collaboration (IMCC) [19].

Indeed, the required increase in energy and luminosity in future high-energy frontier colliders poses serious challenges [1,20]. Without breakthroughs in design and technology, the cost and use of land and energy are likely to increase to unsustainable levels.

The muon collider promises to overcome these limitations and allow a major push to the energy frontier. Circular electron-positron (e^+e^-) colliders are limited in energy by the emission of synchrotron radiation, which increases sharply with energy. Linear colliders overcome this limitation but require the beam to be accelerated to full energy in a single pass through the main linear accelerator and only allow the beams to be used in a single collision [21]. The high mass of the muons attenuates the emission of synchrotron radiation, allowing them to be accelerated in many passes through one ring and to collide repeatedly in another ring. This results in cost effectiveness and compactness combined with a luminosity per beam power that increases almost linearly with energy. Protons can also be accelerated in rings and made to collide with very high energy. However, since protons are composite of quarks and gluons, only a small fraction of their collision energy is available to probe short distance through the collisions of their fundamental constituents. Short distance said to the small spatial scales at which fundamental interactions occur between particles. The effective energy range of a muon collider is therefore equivalent to that of a proton collider with a much higher center-of-mass energy.

Like protons, muons can be made to collide at higher center-of-mass energies in a relatively compact ring without fundamental limitations from synchrotron radiation. However, muon as point-like particles, unlike protons which are composite, their nominal center-of-mass collision energy (E_{cm}) is fully available to produce high-energy reactions that probe length scales as short as center-of-mass collision energy increases ($1/E_{cm}$). Instead, the relevant energy for proton colliders is the center-of-mass energy of the collisions between the quarks and gluons that make up the protons. The partonic collision energy is statistically distributed among the constituent particles and approaches a significant fraction of the nominal energy of the proton collider with very low probability. A muon collider of a given nominal energy and luminosity is thus obviously much more effective than a proton collider of comparable energy and luminosity.

The 2020 update of the European Strategy for Particle Physics (ESPPU) recommended, for the first time in Europe, a research and development (R&D) program on muon collider design and technology. This led to the formation of the International Muon Collider Collaboration (IMCC) [19] with the aim of initiating this program and informing the next ESPPU process on the feasibility perspectives of a muon collider. This will enable the next ESPPU and other strategic processes to assess the scientific justification for a full Conceptual Design Report (CDR) and demonstration program.

In 2021 the European Roadmap for Accelerator research and development (R&D) have published which includes the muon collider [22]. The report is based on consultations with the community at large, combined with the expertise of a dedicated Muon Beam Panel. It also benefited from significant input from the MAP design studies and US experts. The report assesses the challenges of the muon collider and does not identify any insurmountable obstacles. However, the muon collider technologies and concepts for the muon collider are less mature than those for electron-positron colliders. Circular and linear electron-positron colliders already have been built and operated but the muon collider would be the first of its kind.

Muon collider designs assume that muons are produced as the product of a high-powered proton beam incident a target. Most muons are produced by the decay of pions created in the target. The limited lifetime of muons gives rise to several specific challenges. These include the need for rapid production and acceleration of the beam.

Significant progress in the past gives confidence that the goal of building a muon collider will be achieved and that the program will be successful. In particular, the development of superconducting magnet technology has progressed enormously, and high-temperature superconductors have become a practical technology used in industry. Similarly, radio frequency (RF) technology in general has advanced, and experiments have demonstrated the solution to the specific muon collider challenge - operating radio frequency cavities in very high magnetic fields - that was previously considered a showstopper. Component designs have been developed that can cool the initially diffuse beam and accelerate it to multi-TeV energy on a time scale compatible with the lifetime of the muon. However, a fully integrated design has not yet been developed and further research, development and demonstration of the technology is required.

The technological feasibility of the facility is an essential component of the muon collider program, but planning for the use of the facility is equally important. This includes the assessment of the potential of the muon collider to address physics questions, as well as the designing of novel detectors and reconstruction techniques to perform experiments with colliding muons.

Muon Collider Building Timeline

This will need to consider key technical milestones and phases of research and development. The goal [23,24] is to be an MC with a center-of-mass energy of 10 TeV or more. Crossing this energy threshold would allow, among other things, a huge leap forward in the search for new heavy particles compared to the LHC. The ongoing reevaluation of the MC design and the research and development plans allow us to envision a possible path to the realization of the MC and a preliminary technically constrained timeline, as shown in Fig. 2 and explained in greater detail in [25].

The timeline is structured in different phases, with specific attention to critical technical developments. The research and development program for the muon collider will consist of an initial phase, followed by a technical and conceptual design phase. The initial phase will determine the potential of the muon collider and the required research and development program for the subsequent phases. A program of test facilities and equipment prototyping would be carried out over a five-year period, including a prototype cooling cell and the possibility of beam testing in a cooling demonstrator. This program is expected to coincide with the development of high-field solenoids and dipole magnets, which could be used for both the final stages of cooling and collider ring development.

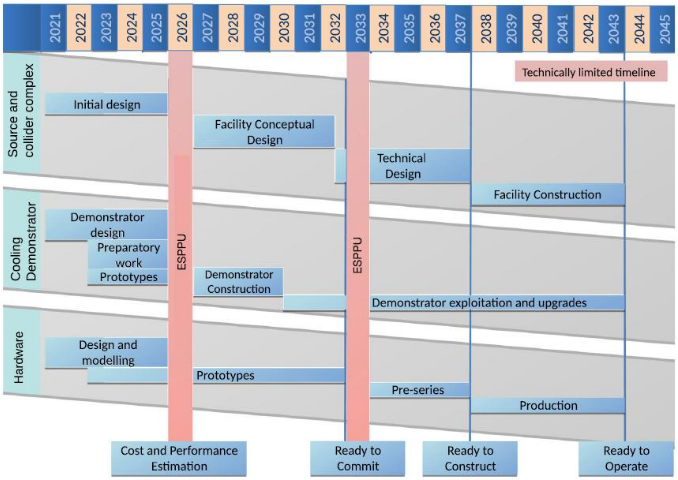

Fig. 2: A technically constrained timeline for the MC research and development program, which would see a 3 TeV muon collider built by the 2040s.

Taken from Ref. Accettura, Carlotta, et al. "Towards a muon collider." *The European Physical Journal C* 83.9 (2023): 1-110. https://doi.org/10.1140/epjc/s10052-023-11889-x

The second phase of the research and development program for the muon collider is followed by technological development. A program of cooling channel prototyping, acceleration system development and systems demonstration be carried out during the mentioned phase. In the third phase of the research and development program for the muon collider is followed by technical design. Full system technical design, validation and testing will be carried out during this phase. The last phase is followed by construction and implementation. Site preparation, infrastructure, major systems installation and integration development program will be applied for the subsequent phases till 2045.

EFT Probes of New Physics

These studies are relevant and timely for several reasons. The results of the first part of the LHC experimental programme suggest that an ambitious leap in energy is required for a fruitful exploration of fundamental interaction physics. In addition, the extension of established *pp* and *ee* collider concepts to higher energies faces severe feasibility challenges in terms of size, cost and power consumption. The second reason for the muon collider is the renewed interest and the recent progress in the technology and design of muon colliders. This includes the results of the Muon Accelerator Program (MAP) studies, which have demonstrated the feasibility of many critical components of the facility [18].

Measuring the properties of the Higgs boson is part of a wider effort to test the Standard Model (SM) with increasing precision and under unprecedented experimental conditions. Valid tests of the SM are those that can conceivably fail, revealing the presence of new physical effects. Theoretical Beyond the Standard Model (BSM) considerations thus provide valuable guidance for the experimental exploration of SM theory. This guidance becomes particularly strong and sharp under the hypothesis that all new physics particles are heavy, so that their observable effects are encapsulated in Effective Field Theory (EFT) interaction operators with an energy dimension greater than four. In this section, we discuss the sensitivity of muon colliders to putative EFT interactions beyond the SM, allowing a systematic and comprehensive exploration of high-energy new physics models.

The hypothesis of new physics may seem pessimistic for a collider project with a high chance of direct detection discovery. Even if it is not precisely described by EFT, relatively light new physics could contribute to the same processes and observables and be detected by the same measurements that we consider here to probe EFT. Even if the new light particles are first discovered in other processes, probing their indirect effects will be an essential step in characterizing their properties and interactions with the SM particles. Or we can say that a characterization program for the newly discovered BSM physics would be like the SM characterization program based on the SM EFT.

A global assessment of the prospects of the muon collider in the search for dark matter (DM) is not yet available. The studies to date, reviewed below, have investigated the potential of the muon collider to explore scenarios where DM is a particle charged under the EW interactions, and its observed abundance in the Universe results from the thermal freeze-out mechanism. This is a compelling possibility, and one in which the muon collider will play an important role. However, the possibility of exploring other interesting scenarios for DM, either through muon collisions or with parasitic experiments, or as a by-product of the muon collider demonstration program, should also be explored.

Our review by considering several studies targeting new physics that preferentially couples to muons, implying an inherent advantage of muon colliders over other facilities. This scenario is, firstly, a logical possibility that muon collisions will allow for the first time to probe systematically and effectively. Furthermore, it is motivated by the stronger coupling of second-generation particles to the Higgs, which typically leads to a stronger coupling to new physics associated with the breaking of the EW symmetry. New physics explaining the structure of the leptonic flavor could also be probed more effectively with muons than with electrons.

The technical feasibility of the muon collider is just one of the key aspects of the project that will need to be studied intensively over the next few years. The muon collider will be the first facility to collide leptons at such high energies, the first facility to collide second generation leptons and the first facility to collide unstable particles. These innovations bring new opportunities and challenges for the use of the muon collider once it is built. Therefore, advances in experimental and theoretical physics and phenomenology are also needed to fully assess and consolidate the physical potential of the muon collider project.

Exploring AQGCs at the Future Muon Collider

The possibilities of searching for AQGCs at the LHC have been explored in [26-30]. The limits for neutral anomalous triplet gauge couplings (ATGCs) at the LHC and $(e^{+}e^{-})$ colliders have been derived in [31,32]. Here we focus on the anomalous quartic gauge couplings (AQGCs) in the diphoton production at the muon collider. This allowed us to study the anomalous vertices $\gamma\gamma\gamma\gamma$ and $\gamma\gamma\gamma Z$. To specify this, let us consider the process (1) which is shown in Figure 3.

$$\mu^{+}\mu^{-} \to \mu^{+}V_1V_2\mu^{-} \to \mu^{-}\gamma\gamma\mu^{+} \quad (1)$$

Which goes via VBF $V_1V_2 \to \gamma\gamma$ $(V_{1,2} = \gamma,\ Z)$. The cross section of the process (1) is given by

$$d\sigma = \int_{\tau_{min}}^{\tau_{max}} d\tau \int_{x_{min}}^{x_{max}} \frac{dx}{x} \sum_{V_1,\ V_2} f_{V_1/\mu^{+}}(x, Q^2) f_{V_2/\mu^{-}}(\tau/x, Q^2)\, d\hat{\sigma}(V_1V_2 \to \gamma\gamma) \quad (2)$$

In the equivalent photon approximation (EPA) [33-38] the polarized distribution of photon inside unpolarized fermion beam $f_{\gamma\pm/f}(x, Q^2)$ is considered. The effective W approximation EWA allows to treat of massive vector bosons as patrons inside the colliding beams [39-47]. In this approach the Z boson has the $f_{Z_{\pm}/f}(x, Q^2)$ and $f_{Z_0/f}(x, Q^2)$ distributions for its transverse (± 1) and longitudinal (0) polarizations [48].

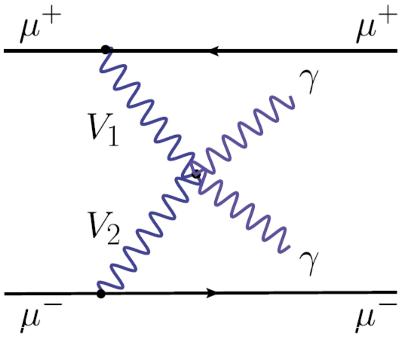

Fig. 3: The Feynman diagrams describing the production of a diphoton in the $\mu^+\mu^-$ collision via vector boson fusion.

Taken from Ref. Amarkhail, H., Inan, S. C., & Kisselev, A. V. (2024). Probing anomalous $\gamma\gamma\gamma\gamma$ couplings at a future muon collider. *Nuclear Physics B*, 116592.

The anomalous helicity amplitudes $M_{\lambda_1\lambda_2\lambda_3\lambda_4}(s, t, u)$ are calculated from an effective Lagrangian that contributes to the anomalous quartic boson vertices [48-49]. s, t and u are Mandelstam variables which have the relation $s + t + u = \sum m^2$. In a broken phase a part of the effective Lagrangian describing anomalous $Z\gamma\gamma\gamma$ interaction looks like [50].

$$\mathcal{L}_{Z\gamma\gamma\gamma} = \zeta_1 F^{\mu\nu} F_{\mu\nu} F^{\rho\sigma} Z_{\rho\sigma} + \zeta_2 F^{\mu\nu} F_{\nu\rho} F^{\rho\sigma} Z_{\sigma\mu} \quad (3)$$

$F_{\mu\nu}$ and $Z_{\mu\nu}$ are field strength tensors. ζ_1 and ζ_2 are anomalous couplings which have the dimension TeV^{-4}.

The total cross sections σ for the collision energy of $\sqrt{s} = 3\ \mathrm{TeV},\ 14\ \mathrm{TeV},\ 100\ \mathrm{TeV}$ are presented in Fig. 4 as a function of the minimal value of the diphoton invariant mass $m_{\gamma\gamma,min}$. We see that for low collision energy $\sqrt{s} = 3$ TeV the total cross section starts to dominate the SM one at approximately $m_{\gamma\gamma} \gtrsim \frac{\sqrt{s}}{2}$. For higher collision energies of $\sqrt{s} = 14$ TeV and 100 TeV it takes place earlier if $m_{\gamma\gamma} \gtrsim \frac{\sqrt{s}}{7}$.

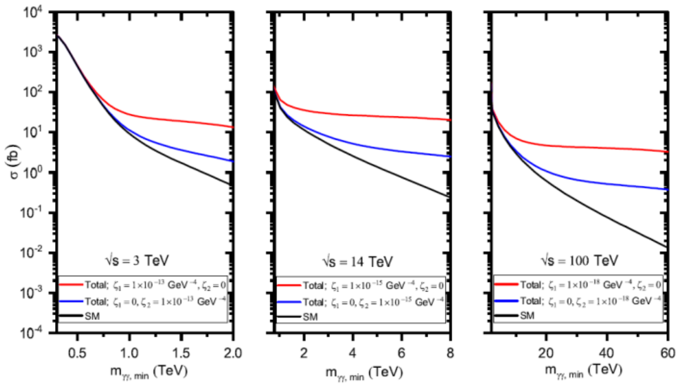

Fig. 4: The total cross sections σ for the diphoton production $\mu^+\mu^- \to \mu^+\gamma\gamma\mu^-$ scattering at the future muon collider versus minimal value of the invariant mass of the photon pair $m_{\gamma\gamma}$. The center-of-mass energy is equal 3 TeV (left panel), 14 TeV (middle panel), and 100 TeV (right panel).

Taken from Ref. Amarkhail, H., Inan, S. C., & Kisselev, A. V. (2024). Probing anomalous $Z\gamma\gamma\gamma$ couplings at a future muon collider. *Nuclear Physics B*, 116592.

Partial wave unitarity requires the relation

$$\left|T^J_{\lambda_1\lambda_2\lambda_3\lambda_4}(s)\right| \leq 1 \tag{4}$$

We know that $T^J_{\lambda_1\lambda_2\lambda_3\lambda_4}(s)$ is related to the partial wave amplitude. Unitarity bounds derived for $\gamma\gamma\gamma\gamma$ anomalous couplings in [48] and for $Z\gamma\gamma\gamma$ AQGCs in [49]. They look like,

$$|\zeta_1| < 2\pi s^{-2}, |\zeta_2| \leq (16\pi/3)s^{-2} \tag{5}$$

As we see, the unitarity demands that the coupling $|\zeta_1|$ must be less than 7.8×10^{-2} TeV^{-4}, 1.64×10^{-4} TeV^{-4}, and 6.28×10^{-8} TeV^{-4} for $\sqrt{s} =$ 3 TeV, 14 TeV, and 100 TeV, respectively. Correspondingly, the unitarity bounds for the coupling $|\zeta_2|$ are 0.21 TeV^{-4}, 4.36×10^{-4} TeV^{-4}, and 1.68×10^{-7} TeV^{-4}. To conclude, unitarity is not violated in the region of AQGCs [48-49].

Conclusion

Muon colliders could provide excellent discovery potential with high precision capabilities. For the purposes of event detection and reconstruction, the challenge that separates $\mu^+\mu^-$ with the e^+e^- counterparts are the beam-induced background. Because muon particles are unstable, they decay and produce electrons, which further interact with the accelerator and detector components. This produces very large multiplicities of mostly soft secondary particles, some of which enter the detector. The hits produced by the secondary particles in the detectors lead to significant challenges in reconstruction and particle detection.

The Comparision of LHC with muon collider, physics goals, advantage, challenges, concept and building Timeline of muon collider has been presented, in addition to preliminary information about muon particle.

The novelty of the subject and the lack of established solutions allow a high rate of progress, but it also requires that experimental and theoretical physics progress in parallel, as progress in one motivates and supports work in the other. This is important, especially at this early stage in the design of the muon collider project.

We have discussed that the anomalous quartic gauge couplings (AQGCs) in the $\mu^+\mu^- \rightarrow \mu^+\gamma\gamma\mu^-$ scattering at the high energy muon collider with unpolarized beams. We have investigated the constraints imposed by partial wave unitarity. It has been shown that it is not violated for the AQGCs values.

The challenging environment of the MC provides a fertile ground for the development of new techniques, from traditional algorithms to applications of artificial intelligence and machine learning, to entirely new computing technologies such as quantum computers.

The physics of the muon collider is still in its infancy. The studies presented in this title represent the first exploration of the topic, but they allow us to identify the relevant issues, questions and directions for rapid progress in the coming years. The muon collider program offers attractive prospects for ambitious, innovative research and development that will advance particle collider physics.

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CHAPTER 4

ADVANCED OXIDATION METHODS FOR SUSTAINABLE ENVIRONMENT: INNOVATIVE APPROACHES IN WASTEWATER TREATMENT

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1. Introduction

The concept of sustainable environment represents a holistic approach aimed at minimizing the negative impacts of human activities on natural systems and maintaining the balanced preservation of ecosystems. This concept encompasses not only environmental protection but also the responsibility to meet the needs of future generations. Sustainability integrates environmental, social, and economic dimensions, prioritizing the efficient use of natural resources and the reduction of environmental pollution (Shammin et al., 2021; Gibberd, 2013). This perspective seeks to enhance human health and quality of life while delivering long-term economic and social benefits (Agyekum-Mensah et al., 2012).

Wastewater management is an integral component of sustainable development. Treating polluted water plays a critical role in preserving water resources, maintaining ecosystem balance, and ensuring public health. However, traditional wastewater treatment methods often fall short of addressing modern challenges. Specifically, contaminants such as micropollutants, pharmaceutical residues, and antibiotic-resistant bacteria demand solutions that exceed the capabilities of conventional technologies (Luo et al., 2014). In this context, advanced oxidation processes (AOPs) emerge as promising and innovative technologies for wastewater treatment (Chatzisymeon et al., 2013; Bracamontes-Ruelas, 2024).

AOPs significantly enhance water quality by ensuring the complete degradation and mineralization of organic pollutants. These methods not only remove contaminants but are also effective in the inactivation of harmful microorganisms (Bairán et al., 2020; Azuma et al., 2022). Moreover, diverse technologies such as photochemical, electrochemical, and plasma-based advanced oxidation processes improve the overall efficiency of treatment systems by rendering wastewater more biologically treatable (Gu et al., 2017; Bracamontes-Ruelas, 2024). AOPs offer a comprehensive solution to enhance water resource security and mitigate environmental impacts (Zhang et al., 2022; Li et al., 2021).

AOPs used in wastewater treatment contribute to ecosystem preservation by enabling the complete degradation of hazardous substances. For instance, photocatalytic AOPs are effective in removing toxic chemicals and disinfecting water (Li et al., 2021). Studies have also demonstrated the effectiveness of AOPs in eliminating micropollutants (Mansouri et al., 2019; Ribeiro et al., 2019; Rekhate and Srivastava, 2020; Ryu et al., 2021; Tufail et al., 2021; Masood et al., 2022; Priyadarshini et al., 2022; Zawadzk, 2023). These processes not only ensure the efficient removal of contaminants but also offer advantages such as energy efficiency and a reduced environmental footprint (Zhang et al., 2022).

The oxidation process involves the release of reactive oxygen species, such as hydroxyl ions (•OH), in sufficient quantities to treat wastewater. Reactive species are free radicals with high redox potential, capable of oxidizing other molecules through self-reduction. These radicals are key to initiating advanced oxidation processes, breaking down complex toxic pollutants into non-toxic, simpler compounds (Saravanan et al., 2022). The hydroxyl radical (•OH), which drives the degradation in advanced oxidation processes, possesses several essential characteristics, including non-selectivity, ease of production, high oxidation potential, and remarkable reactivity. AOPs encompass all catalytic and non-catalytic processes that exploit the high oxidative capacity of •OH and differ primarily in how the radical is generated. These processes are fundamentally based on the *in situ* production of hydroxyl radicals, which rapidly react with most organic compounds (Cuerda-Correa et al., 2020).

In conclusion, the concept of a sustainable environment necessitates the application of innovative technologies like advanced oxidation processes to preserve and sustainably manage water resources. These methods are vital tools for mitigating environmental impacts, safeguarding human health, and ensuring ecosystem sustainability. Future research should focus on enhancing the efficiency of these technologies, reducing their energy consumption, and developing innovative solutions for broader applications (Inam & Offiong, 2021; Ronen & Kerret, 2020; Vezzoli et al., 2018).

2. General Principles of Advanced Oxidation Processes (AOPs)

AOPs are innovative and effective technologies widely utilized in water and wastewater treatment, gaining increasing importance in line with environmental sustainability goals. The primary objective of these methods is to achieve the mineralization of organic pollutants and mitigate their toxic effects. The working principle of AOPs relies on the generation of hydroxyl radicals, which possess high oxidative capacity. These radicals rapidly attack pollutants due to their strong oxidation potential, breaking molecular structures and transforming them into simpler, environmentally benign components (Dai et al., 2012; Dewil et al., 2017).

AOPs are implemented through combinations of chemical oxidants, UV irradiation, homogeneous or heterogeneous catalysts, and electrochemical processes. These methods effectively remove persistent pollutants in water, offering critical solutions where conventional treatment methods fall short. The advantages of AOPs are particularly prominent in challenging processes such as the treatment of industrial wastewater, removal of pharmaceutical residues, and elimination of micropollutants (Sirés et al., 2014; Gopalakrishnan et al., 2023).

3. Fundamental Mechanisms of AOPs

AOPs are fundamentally based on the generation of hydroxyl radicals (•OH) and their reactive behavior. Hydroxyl radicals are among the most powerful oxidants known and can effectively degrade many organic compounds present in environmental water matrices. The mechanism of AOPs can be described through the following processes:

1. Generation of Hydroxyl Radicals:

Hydroxyl radicals are typically produced through the use of oxidants (e.g., hydrogen peroxide or ozone), UV irradiation, iron salts, or combinations of catalysts.

2. Oxidation Process:

The generated hydroxyl radicals react with organic pollutants, breaking chemical bonds and transforming the pollutants into less harmful products.

3. Mineralization:

At the end of the process, the pollutants are often fully converted into harmless end-products such as carbon dioxide, water, and inorganic ions.

4. Types of AOPs

Fenton/Photo-Fenton/Sono-Photo-Fenton Oxidation Processes

Fenton and related processes rely on the production of hydroxyl radicals through the reaction of hydrogen peroxide (H_2O_2) with iron ions (Fe^{2+}) (Equation 1). These methods are particularly effective for removing organic pollutants such as phenols, pesticides, and dyes. The addition of UV irradiation and ultrasound (US) enhances the efficiency of the reaction, enabling a stronger impact on more complex pollutants (Lucena et al., 2020; Vijayalakshmi et al., 2011).

$$H_2O_2 + Fe^{2+} \leftrightarrow Fe^{3+} + \bullet OH + OH^- \quad (1)$$

The most commonly used Fenton reagents are H_2O_2 and Fe^{2+}. These reagents offer significant advantages such as low cost, non-toxicity, and a homogeneous catalytic structure, which eliminates mass transfer limitations. Ferrous iron initiates and catalyzes the decomposition of H_2O_2, resulting in the formation of highly reactive hydroxyl radicals. In AOPs, the •OH radical serves as the primary reactant capable of degrading a wide range of organic compounds through oxidation. The Fenton oxidation process is completed in four steps: (1) adjustment of pH to a low acidic level, (2) oxidation, (3) neutralization, and (4) separation of by-products through coagulation (Yıldız and Cömert, 2020).

When the Fenton process occurs in the presence of UV light, it is referred to as the photo-Fenton process. Under these conditions, Fe^{3+} complexes undergo photolysis to regenerate Fe^{2+} ions, and the Fenton reaction chain is sustained in the presence of H_2O_2. The initial step of photolysis-assisted Fenton reactions involves the formation of •OH radicals. The photoreduction of Fe^{3+} hydroxy complexes into Fe^{2+} under UV irradiation enhances •OH radical production, leading to increased mineralization. The reaction continues until H_2O_2 is depleted, during which the degradation rate remains high (Yıldız and Olabi, 2021). Equation 2 represents the photo-Fenton mechanism (Olabi and Yıldız, 2021).

$$Fe^{3+} + H_2O_2 + h\upsilon \rightarrow Fe^{2+} + OH^- + {}^{\bullet}OH \quad (2)$$

Ultrasound is effectively utilized for the oxidation of organic compounds in water, either as a standalone method or in combination with other processes. This mechanism can be explained through two pathways: (1) the pyrolysis occurring within cavitation bubbles, which is expected to be the primary reaction for degrading polar organic compounds, and (2) the generation of reactive radicals (Yıldız et al., 2023).

The sono-photo-Fenton process can be described by Equations 3–6 (Vaishnave et al., 2014).

$$\bullet OH + HO_2\bullet \rightarrow H_2O + O_2 \quad (3)$$

$$HO_2\bullet + HO_2\bullet \rightarrow H_2O_2 + O_2 \quad (4)$$

By US,

$$H\bullet + H_2O_2 \rightarrow \bullet OH + H_2O \quad (5)$$

$$Fe^{3+} + \bullet H \rightarrow Fe^{2+} + H^+ \quad (6)$$

Ozonation

Ozonation is performed by introducing ozone gas (O_3) into water. Ozone generates hydroxyl radicals (•OH) through direct or indirect reactions within the aqueous medium. This method is an effective approach for disinfection and the removal of micropollutants. Ozonation is particularly significant for eliminating biologically resistant compounds, such as antibiotics and endocrine disruptors (Azuma et al., 2022).

Electrochemical Oxidation

Electrochemical methods enable the direct production of hydroxyl radicals (•OH) at the anode, offering an effective solution for treating high-concentration industrial wastewater. Furthermore, innovative electrode materials and reactor designs are being developed to enhance energy efficiency (Chaplin, 2014).

Electrocoagulation (EC) is a type of electrochemical oxidation in which anodic corrosion releases active coagulants into the solution. The EC process offers several advantages, including high treatment efficiency, the absence of chemical additives, reduced sludge production, and ease of operation. The EC process consists of three main steps:

1. **Electrolytic Reactions at the Electrode Surface:** Formation of active species on the electrode surface.
2. **Formation of Coagulants in the Aqueous Phase:** Production of coagulant species that aid in contaminant removal.

3. **Adsorption and Removal:** Adsorption of soluble or colloidal particles onto the coagulants, followed by their removal through sedimentation or flotation.

The most commonly used electrode materials in the EC process are iron and aluminum (Yıldız and Oral, 2019).

5. Advantages of AOPs

High Efficiency: AOPs offer high oxidation efficiency against a wide range of pollutants, including pesticides, phenols, pharmaceutical products, and endocrine disruptors.

Environmentally Friendly Solution: By enabling the mineralization of pollutants, AOPs minimize the formation of harmful by-products.

Versatility: These processes are adaptable to various types of pollutants, making them suitable for use across diverse industries.

Water Reuse: AOPs enhance the reusability of treated water, contributing to the sustainable management of water resources.

6. Challenges in AOPs and Proposed Solutions

Challenges

The primary challenges associated with AOPs include high energy and chemical requirements. Additionally, the formation of toxic intermediates in some cases can pose a problem. Optimizing reactor designs and conducting scale-up studies are also necessary to ensure the widespread applicability of the technology.

Proposed Solutions

Utilization of Solar Energy: Employing solar energy in photocatalytic processes can significantly reduce energy consumption (Harish et al., 2013).

Development of New Catalysts: Creating more efficient and cost-effective catalysts can help lower operational costs.

Integrated Systems: Integrating AOPs with biological treatment processes can optimize energy and chemical use.

The advancement of AOPs offers significant potential for achieving environmental sustainability and public health objectives. Future innovations, particularly the integration of advanced technologies such as nanotechnology and artificial intelligence, could enhance the efficiency and applicability of these methods. Such innovative solutions are expected to expand the use of AOPs in a broader range of water treatment applications.

7. AOPs as Innovative Solutions in Wastewater Treatment

Advanced Oxidation Processes (AOPs) are increasingly favored as environmentally friendly, efficient, and innovative technologies for treating both industrial and domestic wastewater. AOPs are particularly renowned for their high efficiency in eliminating persistent and non-biodegradable pollutants.

The core function of AOPs lies in the mineralization of contaminants through free radical reactions. These methods offer effective solutions for the removal of both organic and inorganic pollutants. Additionally, they often reduce the toxicity of harmful components, making them less hazardous to the environment.

8. Applications of AOPs in the Treatment of Industrial Wastewater

Advanced Oxidation Processes (AOPs) play a crucial role, particularly in the treatment of industrial wastewater. Industrial effluents typically contain high organic loads, toxic components, heavy metals, and non-biodegradable pollutants. AOPs are highly effective in treating such wastewater as they utilize high-energy oxidants (e.g., hydroxyl radicals) to degrade contaminants. Different AOPs are applied depending on the type of industrial wastewater, and the removal efficiencies vary accordingly. Below, examples of AOP applications in various industrial sectors are provided.

Textile Industry

The textile industry generates wastewater containing significant amounts of pollutants due to the use of reactive dyes and various chemicals during dyeing and printing processes. These wastewaters typically exhibit high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values. AOPs, such as the Fenton process, have demonstrated remarkable success in the effective removal of organic pollutants in these effluents. For instance, a study using the Fenton process reported a 95% COD removal rate in textile wastewater (Hammam et al., 2022). Similarly, another study utilizing photo-Fenton applications achieved a COD removal efficiency of 75% (Piaskowski & Nowak, 2013). These findings underscore the effectiveness of AOPs in treating textile wastewater.

Food Industry

The food industry, particularly sectors such as dairy and juice production, generates substantial amounts of wastewater. While these wastewaters are often biologically degradable, they may contain high levels of organic compounds. AOPs, such as ozonation and Fenton reactions, have proven effective in treating such effluents. In one study, the application of AOPs achieved an 85% COD removal rate in food industry wastewater (Bermúdez et al., 2021). Additionally, another study using the ozonation method reported a 90% removal rate of total dissolved solids (TDS) in food wastewater (Ma, 2024). These results highlight the efficiency of AOPs in managing food industry effluents.

Pulp and Paper Industry

The pulp and paper industry generates wastewater containing significant amounts of organic compounds and chemical substances. Ozonation is commonly employed for treating such effluents, while Fenton and photo-Fenton processes have also demonstrated considerable effectiveness. In one study, ozonation achieved COD removal rates ranging from 65% to 75% in paper industry wastewater (Hermosilla et al., 2014). Additionally, the Fenton process was found to remove 80% of organic compounds in paper wastewater (Hermosilla et al., 2014). These results emphasize the potential of AOPs in treating wastewater from the pulp and paper industry.

Chemical Industry

The chemical industry generates wastewater containing high levels of toxic components and organic pollutants. Advanced oxidation methods, such as the Fenton process, are highly effective in the removal of such contaminants. For instance, a study reported a 90% COD removal efficiency in chemical industry wastewater using the Fenton process (Hammam et al., 2022).

Agriculture and Food Processing Industry

The agriculture and food processing industry produces wastewater containing pesticides and other chemical components. In one study, the Fenton process achieved a 95% removal rate for pesticides, such as atrazine. Additionally, the total organic carbon (TOC) removal efficiency in agricultural wastewater was reported as 35% (Bermúdez et al., 2021).

Hospital Wastewater

Hospital wastewater often contains antibiotics and other pharmaceutical compounds. In a study utilizing ozonation and electro-Fenton methods, the removal efficiency of pharmaceuticals in hospital wastewater was found to be

98% (Somensi et al., 2015). These results highlight the high efficiency of AOPs in treating hospital effluents.

Electronics Industry

The electronics industry generates wastewater containing significant amounts of toxic components. In a study utilizing Fenton and photo-Fenton processes, the removal efficiency of organic compounds in electronic wastewater was reported to be 95% (Piaskowski & Nowak, 2013). These findings demonstrate the high effectiveness of AOPs in treating wastewater from the electronics industry.

Oil and Gas Industry

The oil and gas industry produces wastewater rich in oils and chemical substances. A study employing ozonation reported a 90% removal efficiency for oils in petroleum wastewater (Ma, 2024). Additionally, another study using the Fenton process achieved an 85% removal rate of total organic carbon (TOC) in petroleum wastewater (Bermúdez et al., 2021). These results highlight the significant potential of AOPs in treating wastewater from the oil and gas sector.

Mining and Metal Processing Industry

The mining and metal processing industry generates wastewater containing heavy metals and other pollutants. In a study utilizing AOPs, the removal efficiency of heavy metals in mining wastewater was reported to be 80% (Hammam et al., 2022). These results illustrate the effectiveness of AOPs in treating wastewater from the mining and metal processing industry.

9. Applications of AOPs in Domestic Wastewater Treatment

Domestic wastewater typically contains microorganisms, nutrients, pathogens, and various chemical components. The application of AOPs in treating such wastewater is particularly important for the removal of harmful pathogens and improving water quality. Below are examples of AOP applications in domestic wastewater treatment.

The use of UV radiation is highly effective in the removal of pathogens and harmful microorganisms in domestic wastewater. In one study, UV disinfection reduced the E. coli count in domestic wastewater by 99.9%, decreasing it from 1.5×10^5 CFU/100 mL to 150 CFU/100 mL (Özgüven et al., 2021). This method plays a critical role in making water safe for human health.

Ozonation is highly effective in removing harmful components from domestic wastewater. It facilitates the breakdown of pathogens and some organic pollutants. In one study, ozonation achieved a 90% removal rate of total dissolved solids (TDS) in domestic wastewater (Akçakoca & Gökalp, 2020). This result demonstrates the contribution of AOPs to the treatment of domestic wastewater. Furthermore, this method enhances water quality, increasing its potential for reuse.

The removal of Chemical Oxygen Demand (COD) is an important indicator of water quality. In a study using AOPs, the COD removal rate in domestic wastewater was found to be 85% (Katip, 2018). This highlights the high efficiency of AOPs in treating domestic wastewater.

Domestic wastewater contains pollutants that are biologically non-degradable. The effectiveness of AOPs in removing these pollutants has been found to be 95% in several studies (Seçkin et al., 2021). This underscores the significant role of AOPs in the treatment of domestic wastewater.

The removal of micropollutants is critical in the treatment of domestic wastewater. In a study employing AOPs, the removal efficiency for pharmaceuticals (methotrexate) was found to be 98% (Güller & Balcı, 2018). Additionally, another study using ozonation achieved a 95% removal rate for pesticides (atrazine) (Beduk et al., 2021). These results highlight the advantages of AOPs in effectively eliminating micropollutants.

10. Innovative Approaches and Emerging Technologies

AOPs and other wastewater treatment technologies are of critical importance in the conservation of water resources and the achievement of environmental sustainability. This section will discuss advancements in AOPs, including newly developed catalysts and reactor designs, energy-efficient methods, cost reduction strategies, and the integration of nanotechnology and photocatalytic membrane technologies. These innovations are key to enhancing the efficiency and sustainability of wastewater treatment processes.

Newly Developed Catalysts and Reactor Designs

In recent years, significant research has been conducted on new catalysts and reactor designs to enhance the effectiveness of AOPs. For example, Salamanca and colleagues reported that hollow fiber forward osmosis membranes achieved a 99% efficiency in removing emerging contaminants from urban wastewater (Salamanca et al., 2022). These membrane technologies represent a significant innovation in the effective removal of pollutants. Additionally, newly developed photocatalysts work efficiently under UV light, providing high removal efficiency in water treatment. The development of catalysts used in AOPs has become an important area for improving treatment processes. For instance, titanium dioxide (TiO_2)-based photocatalysts are commonly used to produce hydroxyl radicals under UV light. Modified TiO_2 catalysts offer higher efficiency and durability (Ates-Genceli et al., 2018). Furthermore, nanoparticles developed using nanotechnology are revolutionizing reactor designs. For example, nanoparticle-based membranes provide higher permeability and selectivity in water treatment, thus accelerating the purification processes (Kılbaş, 2023).

Energy-Efficient Methods

Energy efficiency is a crucial factor in wastewater treatment. In a study by Geng, it was found that innovative methods used in the treatment of domestic wastewater reduced energy consumption by 30% (Geng, 2023). Additionally, anaerobic membrane bioreactors (AnMBRs) offer higher efficiency compared to traditional high-rate anaerobic reactors, thus reducing energy consumption (Dereli et al., 2018). These innovative methods present a significant opportunity to enhance energy efficiency in wastewater treatment. New approaches are also helping reduce costs by lowering energy consumption. For instance, solar-powered photocatalytic systems contribute to energy savings in AOP processes and enhance environmental sustainability (Sahin et al., 2021). Moreover, the use of hybrid systems, when combined with traditional methods, has been shown to achieve higher removal efficiencies with lower energy consumption (Unlu, 2022). Such strategies reduce both environmental impacts and operational costs.

Cost Reduction Strategies

Various strategies have been developed to reduce the costs associated with AOPs. For example, Collivignarelli and colleagues reported that the cost of sludge management in wastewater treatment plants accounts for about 50% of the total operating costs (Katsoyiannis & Torretta, 2021). Therefore, developing new methods to reduce sludge production could significantly lower costs. Additionally, optimizing biological treatment processes in conjunction with AOP integration has the potential to reduce overall costs (Collivignarelli et al., 2019). These strategies highlight the importance of cost-effective approaches for enhancing the economic sustainability of wastewater treatment.

Developments in AOPs with Nanotechnology and Photocatalytic Membrane Technologies

Nanotechnology presents a significant innovation in wastewater treatment. Nanoparticles enhance the efficiency of reactors by offering a high surface area for pollutant removal. For instance, Zhang and colleagues reported that photocatalysts developed using nanotechnology achieved 99% efficiency in water treatment. Additionally, photocatalytic membrane technologies play a crucial role in effectively removing pollutants (Salamanca et al., 2022). Nanoparticles are used to provide higher efficiency and effectiveness in water purification. For example, nanofiber membrane technologies offer high separation efficiency and energy savings in water treatment (Tüylek, 2018). Furthermore, photocatalytic membranes provide an effective solution for removing pollutants from water. These membranes operate under UV light to mineralize harmful components in the water (Eren, 2023).

Performance Evaluation of Catalysts

The performance of newly developed catalysts is assessed based on various parameters. For instance, a study examined the effectiveness of TiO_2-based photocatalysts under different pH levels and temperature conditions. The results indicated that removal efficiencies of up to 90% were achieved under specific conditions (Akgül & Turan, 2020). Such performance evaluations are critical for optimizing AOP processes.

Innovations in Reactor Designs

Reactor designs are continuously evolving to improve the efficiency of AOP applications. For example, microreactors provide more surface area and better mixing, leading to more effective results in AOP processes (Can & Arabaci, 2021). Additionally, modular reactor designs offer flexibility by allowing easy adaptation to different application areas, thus enhancing their versatility.

Emerging Technologies and Application Areas

Emerging technologies are offering new application areas in wastewater treatment. For example, microalgal systems are being used for both pollutant removal and biomass production in wastewater treatment (Samiotis et al., 2018). These systems contribute to environmental sustainability and provide new opportunities for energy production. Additionally, photocatalytic membranes offer high efficiency in wastewater treatment while reducing energy consumption (Salamanca et al., 2022).

In conclusion, innovative approaches and emerging technologies play a significant role in wastewater treatment. Newly developed catalysts, reactor designs, energy-efficient methods, cost-reduction strategies, nanotechnology, and photocatalytic membrane technologies enhance the effectiveness of AOPs and support environmental sustainability. Therefore, continued research in this field will lead to more effective and sustainable water treatment solutions in the future.

11. Environmental and Economic Assessment

Advanced Oxidation Processes (AOPs) play a significant role in the environmental impact assessment, cost-effectiveness, and implementation challenges of wastewater treatment. This section will address the environmental impacts, cost-efficiency, scalability issues, and application challenges of AOPs.

Environmental Impact Assessment

The environmental impacts of AOPs are evaluated based on factors such as energy consumption, by-products, and carbon footprint. AOP processes generally require high energy consumption. In some cases, the by-products of AOPs can be toxic, posing environmental risks. For instance, methods like ozonation and chlorination can lead to the formation of halogenated organic compounds as by-products (Dong et al., 2019).

Carbon footprint is also a critical parameter for assessing the environmental impact of AOPs. The carbon footprint of AOP applications varies depending on the energy sources used and the efficiency of the processes (Keyter et al., 2020).

Cost-Effectiveness and Scalability Issues of AOPs

The cost-effectiveness of AOPs depends on the type of methods used and the application area. For example, the cost of wastewater treatment using the Fenton method was found to be 30% lower than that of traditional biological treatment methods (Frontistis, 2018). However, the scalability of AOPs faces some challenges. In particular, the equipment and energy costs associated with large-scale applications can affect the economic sustainability of AOPs (Malvestiti et al., 2018).

Strategies are being developed to enhance the cost-effectiveness of AOPs. For instance, the integration of recovery systems reduces the cost of chemicals used and minimizes waste generation (Epelle et al., 2023). Additionally, the use of local resources contributes to reducing operational costs, thereby enhancing sustainability.

Challenges in the Application of AOPs

The application of AOPs is associated with several challenges, including high energy consumption, the formation of by-products, and process control. The effectiveness of AOP processes depends on parameters such as pH, temperature, and reactor design (Marín-Marín, 2023). The control of such variables presents significant challenges in AOP applications. Furthermore, by-products generated during AOP processes can sometimes be toxic, posing potential environmental risks (Dong et al., 2019).

The challenges associated with the application of AOPs are also linked to regulatory requirements. The environmental impacts and by-products of AOP processes may be subject to various regulations. For example, some countries have implemented regulations that consider the environmental effects of the chemicals and by-products used in AOP processes (Shewa & Dagnew, 2020). This can limit the scope of AOP applications and increase costs.

In conclusion, the environmental and economic assessment of AOPs plays a crucial role in determining the effectiveness and sustainability of these methods. Evaluating environmental impacts, cost-effectiveness, scalability issues, application challenges, and regulatory requirements are critical for the development of innovative approaches in this field. Enhancing the effectiveness of AOPs and finding broader application areas should be the focal point of future research.

Conclusion

Advanced Oxidation Processes (AOPs) play a critical role in contributing to a sustainable environment through their efficient application in water treatment. These methods significantly enhance water quality by effectively removing organic pollutants, micro-pollutants, and pathogens. One of the key advantages of AOPs is their ability to increase the potential for water reuse, especially in the treatment of domestic wastewater, enabling its safe application in agriculture and industrial sectors.

Innovative treatment technologies are crucial for achieving sustainable environmental management. Compared to conventional methods, AOPs offer higher efficiency and effectiveness, making a notable contribution to improving water quality. Additionally, the development of new catalysts and reactor designs has led to increased AOP efficiency and reduced costs. The use of nanotechnology, such as nanoparticles and photocatalytic membrane technologies, further boosts the effectiveness of AOPs while supporting environmental sustainability.

In the future, AOPs and other innovative water treatment technologies are expected to expand into a broader range of applications. Methods that enhance energy efficiency and strategies for cost reduction will facilitate the widespread adoption of AOPs. Moreover, the development and optimization of AOPs, aligned with environmental sustainability goals, will be pivotal for safeguarding water resources and ensuring public health.

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CHAPTER 5

OPTIMISED CROPS FOR THE SOIL WITH ARTIFICIAL INTELLIGENCE TECHNIQUES FORECAST

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INTRODUCTION

Agriculture, which has found a place in human life since the existence of humanity, has been one of the most important income and development sectors of countries. With the increasing population, the importance of agriculture and production has also increased significantly. However, decreasing water resources and increasing water use are among the problems that need more attention as they cause negative effects on agriculture. Agriculture has a very important place in terms of ecosystem sustainability. Agricultural areas function as a centre for the life of plant and animal species and are important for the healthy functioning of the ecosystem. When the processes in agricultural practices are applied correctly, significant changes can be achieved in productivity, water and air quality. It also has a major role in shaping values in social and cultural areas. The sustainability of the agricultural system depends on the preservation and transfer of traditional knowledge. Along with technological developments, important breakthroughs made in the agricultural sector provide serious support to the development of countries. In line with the developments made in this field, it offers positive activities such as increase in yield, improvement in climate change, and protection of resources.

Smart farming systems address issues such as forecasting and analysis as it allows monitoring of conditions such as climate status, soil characteristics, harvest time, harvest yield status, disease information, crop status and number. IoT systems (Internet of Things) have become popular in all areas of agriculture. Livestock, greenhouse control, farm tracking are used in such tasks as more and more, providing convenience to users [1]. The sensors, which are used a lot in smart agriculture and are important in collecting data, are generally used in collecting data from parameters such as temperature measurement, humidity measurement, motion measurement, plant condition, soil element measurement. Due to the mistakes made in agriculture, negative effects such as yield loss in the soil, inability to get the desired harvest, and harvest time variability occur. The biggest mistake is planting different crops that are not suitable for the soil and climatic conditions to be planted instead of the crops that can grow in the soil. Therefore, these major problems arise. Due to these problems, the producer suffers financial losses and on the other hand, the necessary products (water, fertilizer, seed, etc.) used in the production of the product are wasted. In certain regions, while there may be two harvests per year depending on the climate, but it is reduced to one with the wrong choice of agricultural products. In addition, the yield of agricultural products are faling the product due to climate sensivity (Burak et al.,2022).

In this article, an artificial intelligence-based study has been carried out that can be made available to farmers and producers and will enable more efficient production by taking into account soil properties. In this study, a system was developed using machine learning and deep learning algorithms. In the study, the optimal crop that can be grown in the region was estimated according to soil and climate data. The reason for this study is aimed to produce the crops that the producers will grow in their environment with a more accurate selection. With this study, it is aimed to contribute to the increase in yield by selecting different products according to the soil in each region and to facilitate the work of the producers. The aim of the study is to find out which method will give a higher prediction result by using machine learning and deep learning algorithms and to use it for the system. In the application part of the study, the most suitable crops to be grown were determined by using the data set taken from the Kaggle data site and containing the characteristics of the soils in India. With this data set, machine learning and deep learning algorithms were used to predict the optimal crop result for the soil. In this process, descriptive statistics and statistical analyses were also performed by using data graphics. The other sections of the study are as follows. After the introduction, the literature section of previous studies on agriculture and artificial intelligence is given. Then, the material method section is presented in which the methods used are briefly described. In the fourth section, the application and finally the conclusion section is given.

2. LITERATURE REVIEW

Multiple products and research have been conducted for improvements in agricultural systems. These studies have been carried out to eliminate multiple problems such as saving time, more control over production, predicting production and developing strategies, and reducing costs. These studies give great importance to the rapid development of agricultural systems.

An exemplary IoT-Agro system has been implemented on a Colombian farm to help farmers with tasks such as harvest time planning according to climate change, reducing diseases based on the use of farm data, and annual crop forecasting. Different algorithms such as Decision Trees, Artificial Neural Networks, Support Vector Regression and Random Forest were used in the system to predict coffee production (Rodriguez et al., 2021).

In order to be used in image processing techniques, fruit and vegetable coordinates and Cartesian coordinates were calculated with the data received from the Kinect sensor. With these calculations, fruit and vegetable locations were determined (Mu et., 2017).

A study was conducted using the AlexaNet architecture in CNN for the detection and tracking of plant diseases. PlantVillage dataset with 54,306 images of 14 different species and 26 diseases was used in the study. AlexaNet gave 99.11% accuracy and AlexaNet architecture was used in disease detection studies (Turgut et al., 2019).

Air temperature, which has an important place in agriculture, is an important parameter for production and cannot be ignored. So, it is very important for farmers to know the next air temperature and values. With these values, which will be known for the future, the producer will be able to develop a new strategy in production and the harvest will be maximized.. In the study, temperature, humidity, wind speed and wind direction information were collected by sensors and recorded in the database. The data stored on the created database were processed by artificial neural network models (ANN), K-Nearest Neighbors (KNN) and Random Forest (RF) algorithms and network models were created. As a result of these models, the prediction rate was 87% (Duman and Kayaalp, 2022).

Plants have been of great importance in human life for many years. For this reason, plants have an important place in many sectors. The rose plant, called pink oil rose, has become a very valuable plant in the perfume and food sectors due to its pungent and intense scent. In this study, machine learning and deep learning algorithms were used to classify the oil rose by examining the harvest and non-harvest status according to the data obtained. Images from rose gardens were used as the dataset. (Kadıoglu e al., 2022).

Dry beans are a type of legume that can be grown in cold climates or hot climates depending on the type. According to the data, 27.5 million tons of dry beans were produced in the world in 2020. 7 farklı kuru fasulye çeşidi ile 13.611 adet kuru fasulye örneği alınmıştır. Unfortunately, seed types are unfortunately confused due to the fact that there is more than one different seed type. In this study, dry beans were classified. There are 16 features belonging to the beans and the model performance was tried to be improved with the feature selection algorithm and as a result, the model accuracy rate was 98.2% (Bayrakcı et al., 2021).

Water problem, which is one of the most important problems, gives a big problem to the agricultural sector where it is used the most. The drip irrigation method used in agriculture provides less water use than normal. In the study, a dataset was created using data such as provinces, districts and plant species due to the varying water demand of each plant. With the artificial intelligence models used over this dataset, the amount of water consumed was estimated.The results were also output with a prepared interface (Burges, 1998).

3. MATERIAL AND METHOD

3.1. Datasets and Parameters

The dataset used in the study was found and used through the Kaggle website (URL: https://www.kaggle.com/datasets/atharvaingle/crop-recommendation-dataset). This dataset of Indian soil and climate data includes rainfall, humidity, soil-fertilizer information. The dataset in Table 1 shows the names of crops suitable for cultivation with data from different soils and regions.

Table 1. Parameters and data of the dataset.

	N	P	K	temperature	humidity	ph	rainfall	label
0	90	42	43	20.879744	82.002744	6.502985	202.935536	rice
1	85	58	41	21.770462	80.319644	7.038096	226.655537	rice
2	60	55	44	23.004459	82.320763	7.840207	263.964248	rice
3	74	35	40	26.491096	80.158363	6.980401	242.864034	rice
4	78	42	42	20.130175	81.604873	7.628473	262.717340	rice
...	...	...	...	...	...	...	...	...
195	90	57	24	18.928519	72.800861	6.158860	82.341629	maize
196	67	35	22	23.305468	63.246480	6.385684	108.760300	maize
197	60	54	19	18.748267	62.498785	6.417820	70.234016	maize
198	83	58	23	19.742133	59.662631	6.381202	65.508614	maize
199	83	57	19	25.730444	70.747393	6.877869	98.737713	maize

The dataset consists of 8 parameters. 7 of them are independent and 1 of them is dependent parameter. In the dataset consisting of 2200 data, there are soil Nitrogen value (N), soil Phosphorus value (P), soil Potassium value (K), soil acidic-basic value (ph), ambient temperature value (temperature), ambient humidity value (humidity), rainfall value per mm (rainfall) values. The dependent variable fruit and vegetable variable (label) includes 22 different crops.

3.2. Data Analysis

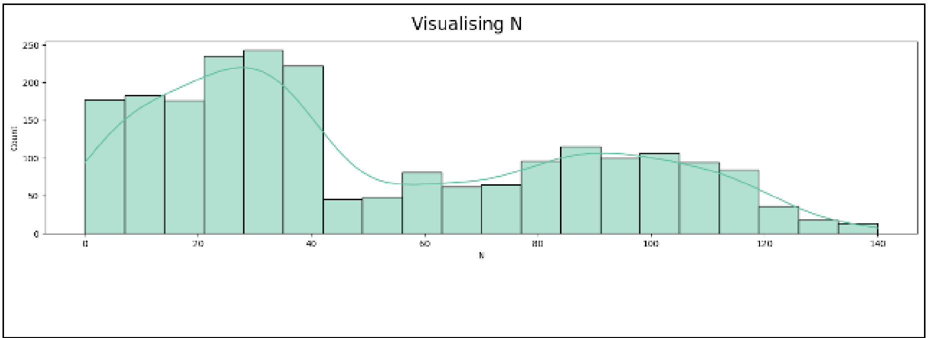
Before using the dataset on the model, descriptive statistics were first calculated to better understand the dataset and to see the results numerically. Obtained values such as mean, variance, etc. of the data and given Table 2. Histogram graphs of all variables are shown in Figure 3.

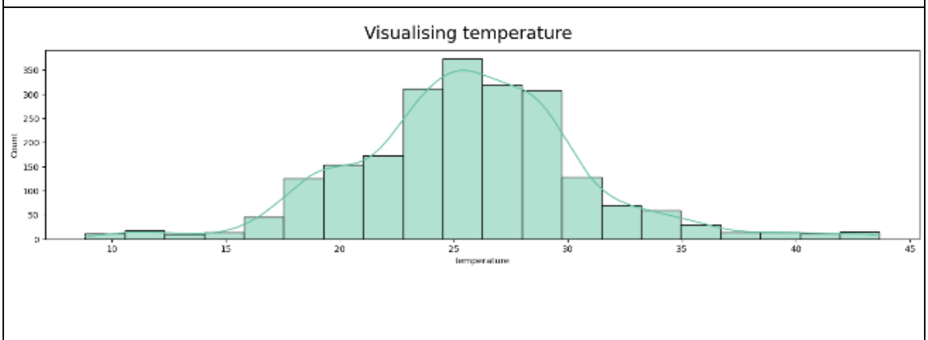
The values in Table 2 are the descriptive statistical values of the data set. The initial analysis values were created by using the values in this table. While the average of the element values varied between 48-53, the temperature was 48 degrees, humidity was 71, pH was 6.50 and precipitation per mm was 103 and the other values are seen above.

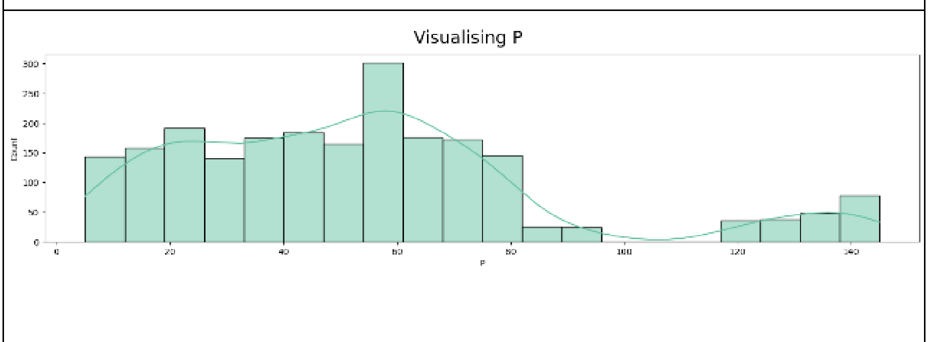
Table 2. Descriptives statistics of the dataset.

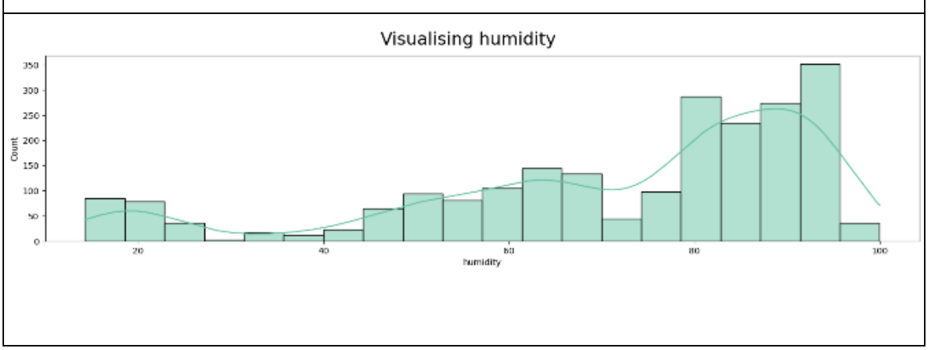
	N (%)	P (%)	K (%)	Temperature (°C)	Humidity (g/m3)	pH (0-14)	Rainfall (mm)
Count	2200.00	2200.00	2200.00	2200.00	2200.00	2200.00	2200.00
Mean	50.5518	53.3627	48.1490	25.6162	71.4817	6.4694	103.4636
Std	36.9173	32.9858	50.6479	5.0637	22.2638	0.7739	54.9583
Min	0.000	5.000	5.000	8.8256	14.2580	3.5047	20.2112
25%	21.000	28.000	20.000	22.7693	60.2619	5.9716	64.5516
50%	37.000	51.000	32.000	25.5986	80.4731	6.4250	94.8676
75%	84.2500	68.000	49.000	28.5616	89.9487	6.9236	124.2675
max	140.000	145.000	205.000	43.6754	99.9818	9.9350	298.5601

The values in Table 2 are the descriptive statistical values of the data set. The initial analysis values were created by using the values in this table. While the average of the element values varied between 48-53, the temperature was 48 degrees, humidity was 71, pH was 6.50 and precipitation per mm was 103 and the other values are seen above.


Visualising N
Count
N


Visualising temperature
Count
temperature


Visualising P
Count
P


Visualising humidity
Count
humidity

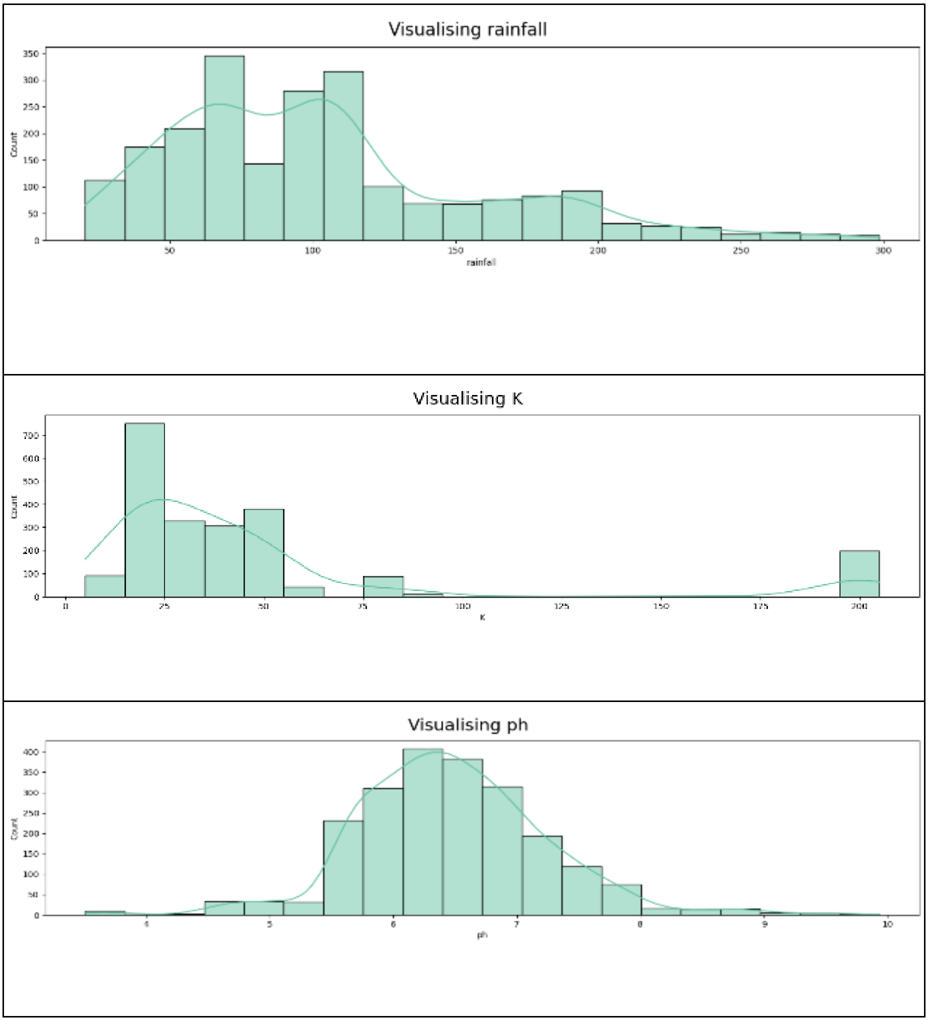
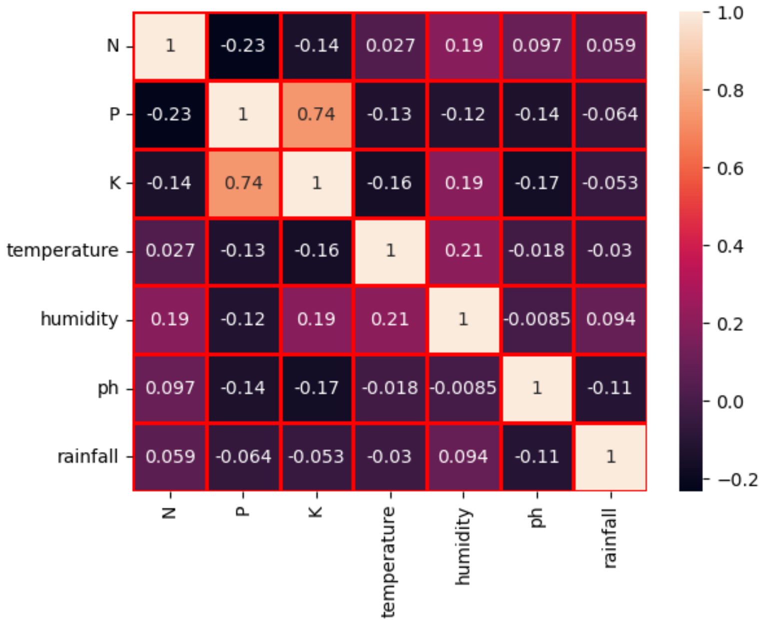


Figure 1. Histogram graph of the variables.

Table 3. Correlation Matrix for datasets.



The Table 3 shows the correlation coefficients between the parameters. The meaning here is to show the connection between the parameters and to show the positive and negative interaction between them. According to Table 2, there is a high positive correlation of 0.74 only between P and K. There is no significant correlation between other variables.

3.3 Support Vector Regression

Support vector regression is a kernel-based tool for classification and regression that is widely used [9]. The working logic is to compute a linear function in the input space to higher dimensions where the input data on the nonlinear functions are mapped [10]. Support vector regression is one of the models applied to both classification and regression problems. The aim of support vector regression is to surround the data points with error. Error refers to how mismatched the data points are in the plane. Support vector regression makes predictions by minimizing these errors.

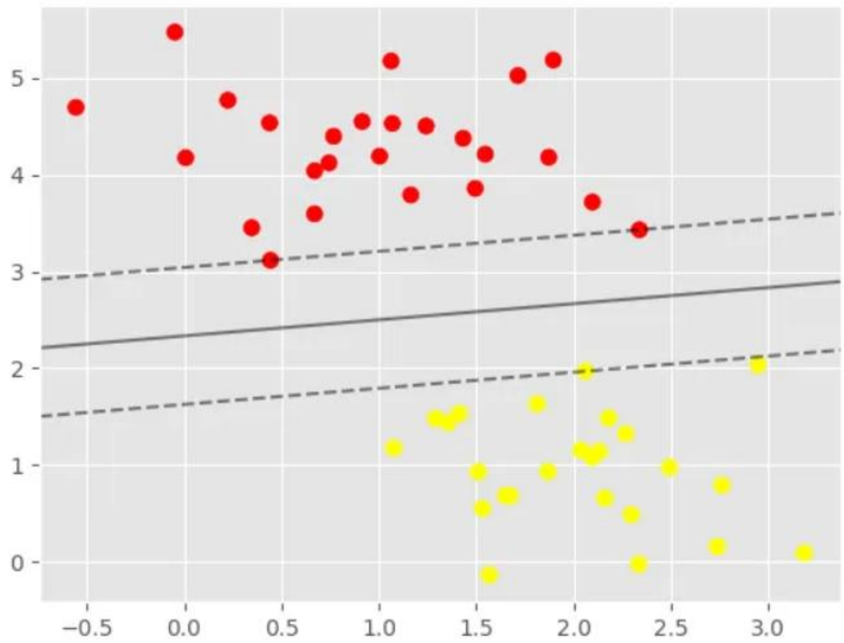


Figure 2. Graph with data classified in Support Vector Regression [11].

The figure 2 shows that two different datasets are classified. The support lines are drawn based on the confirmation values selected from the two datasets. The final regression line to be drawn with these lines is drawn more accurately. Among the major advantages of support vector regression is the absence of excessive learning error. Thus, the new data to be entered into the model are better adjusted and the memorization problem is reduced. On the other hand, support vector regression, which has a robustness against outliers, can be further enhanced with the hyperparameter function to be selected.

3.4 Decision Trees

Decision Tree algorithm, which is one of the easy-to-understand machine learning algorithms, is an algorithm applied on categorical and continuous data that is non-linear and suitable for classification and regression [12]. Named after its tree-like flowchart, the attribute that divides the target into categories and separates the classes is set as the root.

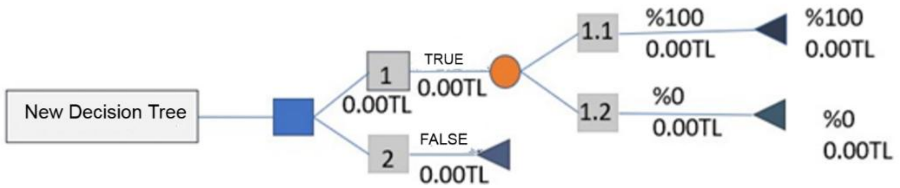


Figure 3 : An example Decision Tree schematic [13]

3.4 Artificial Neural Networks

Artificial neural networks (ANNs, ANNs) are an evolving machine learning model that replicates the way the human brain works. These models are generally used to solve complex patterns with many inputs more easily and quickly. Artificial neural networks mathematically model nerve cells and neurons in the brain.

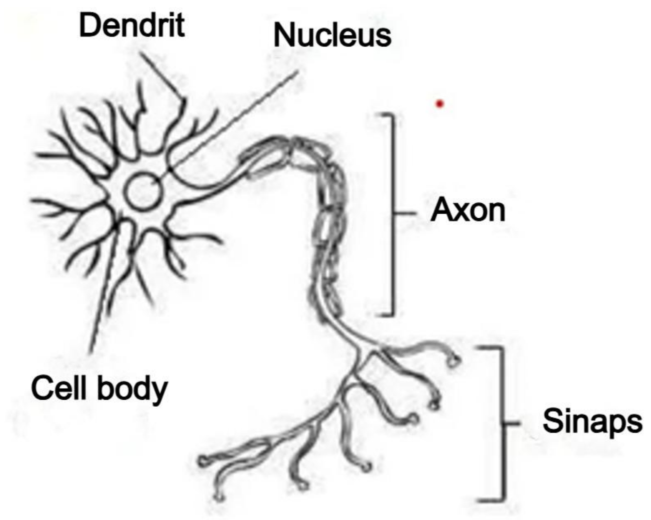


Figure 4. Neural network of the human brain.

Figure 4 shows a neural network of the human brain and its parts. The working principle of an artificial neural network is the same as that of a neural network in the human brain. Neural networks, made up of neurons, receive inputs, process the inputs and output the outputs. The neurons process the inputs by multiplying them by their pain values and applying the appropriate activation function. At the end of the process, the output of the neuron is determined according to the neural network. Artificial neural networks are shaped in three basic layers by organizing neurons in layers. (https://aoyilmaz.medium.com/yapay-sinir-a%C4%9Flar%C4%B1-derindeki-g%C3%BCc%C3%BC-anlamak-54833ef38a3e)

1. Input Layer : The first layer, the input layer, is the entry point of data into the network. These inputs are transferred to neurons and processed (https://aoyilmaz.medium.com/yapay-sinir-a%C4%9Flar%C4%B1-derindeki-g%C3%BCc%C3%BC-anlamak-54833ef38a3e). There are as many cells in this layer as there are inputs and the inputs are transmitted to the hidden layer without any processing.
2. Hidden Layer : Hidden layers, which can be more than one, receive inputs, process them and transmit the result to the next layer. Each hidden layer can contain more neurons to represent more complex features (https://aoyilmaz.medium.com/yapay-sinir-a%C4%9Flar%C4%B1-derindeki-g%C3%BCc%C3%BC-anlamak-54833ef38a3e). The number of cells in the hidden layer can vary from network to network. The number of cells in the hidden layer is independent of the number of inputs and outputs.
3. Output Layer : The last layer, the output layer, provides the outputs that produce the result of the network. It is commonly used for classification and regression tasks (https://aoyilmaz.medium.com/yapay-sinir-a%C4%9Flar%C4%B1-derindeki-g%C3%BCc%C3%BC-anlamak-54833ef38a3e). Each output cell has one output. Each cell is connected to all cells in the previous layer.

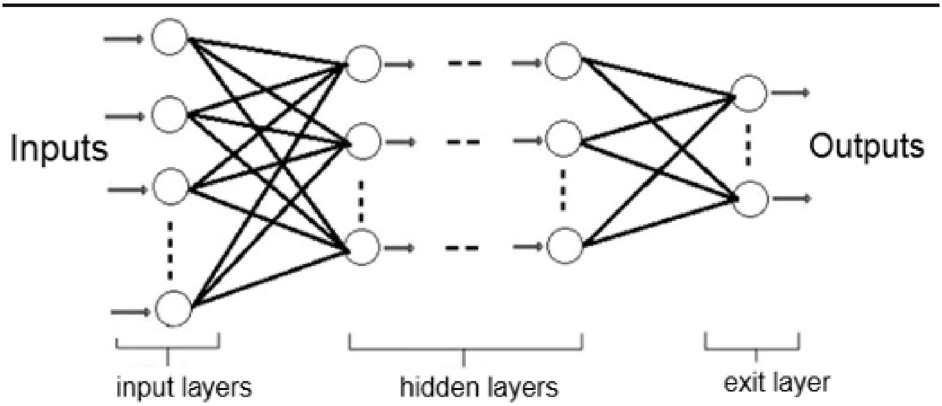


Figure 5. An example model with layers.

3.4.1 Classification in Artificial Neural Networks

Artificial neural networks are classified according to their structure and learning algorithms.

Class for structures : It works as feed-forward and feed-back. In feed-forward structure, cells are in regular layers from input to output. The information arriving at the network is processed at the input layer and then passes through the hidden layers and the output layer respectively. In the feedback structure, the cell output is not given only as input to the next layer. It can be given as input to any cell in the previous layer.

Class for Learning Algorithms : It is divided into three as supervised, unsupervised and reinforcement learning. In supervised learning, the neural network is trained before it is used. In unsupervised learning, there is no advisor, etc. to help the system learn. In reinforcement learning, input data is applied to the network and the result is evaluated by the advisor. By applying a reward and punishment system, network weights are strengthened.

4. STUDY AND METHOD

In this study, machine learning algorithms such as Support Vector Regression and Decision Trees as well as Artificial Neural Networks were used. The aim of this study is to compare and analyze the neural network to be designed through artificial neural networks with other machine learning algorithms.

Jupyter Notebook and Spyder3 were used as the working environment for the code. Used are Tensorflow, Scikit-learn, Keras, Matplotlib, numpy, pandas, seaborn library. These libraries were used for visualization, data preparation, data analysis, using machine learning models, creating and training artificial neural networks.

Before the models were used, the dataset was made usable by editing and checking the dataset. In order to learn and remove missing values in the dataset, we first searched for missing data within the parameters. The result showed that there was no missing data.

Table 4. Number of missing data for parameters.

N	0
P	0
K	0
Temperature	0
Humidity	0
Ph	0
Rainfall	0
Label dtype	int64

In order to make it ready for use for machine learning and artificial neural network, the dataset was separated into training and test dataset. 80% of the entire dataset was allocated for training data and 20% of the entire dataset was allocated for test data. The dependent variable was set as the fruit and vegetable names (label) parameter and the independent variables were set as all the remaining parameters (N,K,P,ph,temperature,humidity,rainfall).

Support vector regression, Decision Trees and Artificial Neural Networks were run on the dataset ready for use on the models. Before using support vector regression, the MinMaxScaler feature from the scikit-learn library was used equaiton (1) to make the data more meaningful and the results more defined. This method ensures that the data is within a certain range. This range is used by setting it between 0 and 1.

$$Xscaled = \left(\frac{X - Xmin}{Xmax - Xmin}\right) * (max - min) + min \quad (1)$$

Our dependent variable (label) was labeled as y_test and y_train and our independent variables were labeled as x_test and x_train. The 20% allocated in the test data was changed between 15% and 25% according to the results of the estimation. In the decision tree model, the max_depth value (maximum depth) was tested in increments of 5 between 5 and 30 and the optimum value was selected. In Support Vector Regression, the optimal value was selected using degree values of 3,5 and 7.

In Artificial Neural Networks, the dependent variable label parameter was quantified. For this purpose, categorical values in the label parameter were converted into numerical values. For this, the LabelEncoder feature in the scikit-learn library was used. With this feature, categorical data is converted into numerical data (0,1,2 etc.) and each category is assigned a numerical value. After this transformation, an artificial neural network model was created. In the model, 4 layers were created, 32 neurons were used in the input layer and 32, 64, 128 and 256 values were used in the intermediate layers. Relu and softmax activation functions were used as activation functions. The sparse categorical crossentropy function was used as the loss function in the model compilation. The epoch (update of weights) value in the model was chosen as 50.

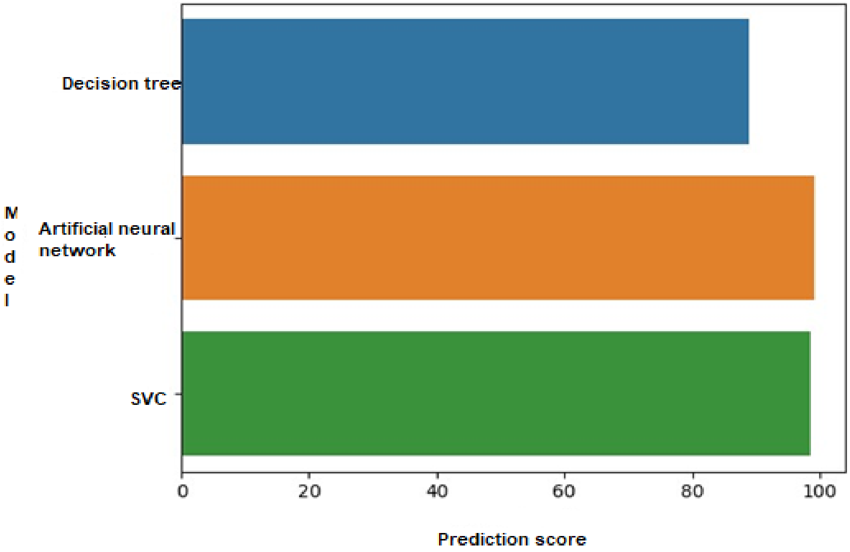


Figure 6. Prediction scores of the models and neural network used.

As a result of the predictions, the Decision Tree scored 88.63%, Support Vector Regression 98.63% and Artificial Neural Network 99.010%. According to the comparison, the highest accuracy rate was found with the designed Artificial Neural Network.

4.1 Crop Predict With Models

The prediction scores on the models show how accurate the models are. The new values to be entered through the parameters or the values selected from the dataset will produce the result when the prediction process is performed with the models made. With the data group to be selected from the values in the dataset, process prediction and observation of the prediction result were made.

```
prediction_values = df.sample(n=1)
print(prediction_values)
```

```
     N   P   K  temperature   humidity        ph    rainfall label
61  83  58  45    25.755286  83.518271  5.875346  245.66268  rice
```

Figure 7. Selected values.

The values selected are for rice. This plant was randomly selected and used in the model. When these selected values are predicted using Decision Trees, Support Vector Regression and Artificial Neural Networks, the result is still rice. The reason for not getting different results is due to the high prediction scores. As a result, correct predictions were made in these 3 processes and correct predictions were made over the entered values.

5. CONCLUSION AND DISCUSSION

In the study, prediction scores were found by processing the data collected with machine learning models. The success rates of these predictions varied according to the model and the highest score was found in the designed Artificial Neural Networks. However, the other models did not have a low prediction score and all the models used had a success rate above 90%. These estimation scores are acceptable and can be considered high value. The main purpose of the study was to compare the prediction scores by comparing models of artificial neural networks that can be created and regulated with stationary machine learning models. In the study, this evaluation was obtained and artificial neural networks gave the highest score.

With these models and forecasts developed, the next generation of intelligent agricultural systems will be designed and made available to producers, and the potential to make a serious difference in productivity increase is very high. With these increasingly advanced artificial intelligence systems, increasing use of agricultural systems in both grounded and landless agricultural systems is a great advantage for production. In other ways, automation systems developed for agricultural systems, image processing and disease detection, harvest quantity estimation, agriculture map geographically, etc, they have great importance as this study, which is done in studies such as fruit-vegetable production estimation. These works for agricultural production will enable the next generation to continue production easily in cities and villages without breaking off and cooling, and will be transferred to future generations by providing ease of production.

The data used in this study was taken from the Kaggle site and the values were compared with the forecast scores. With these datasets that will be obtained by collecting users' own data instead of ready-made datasets and will have more parameters (N,P,K, temperature, humidity, ph, etc, data other than rain) increase the number of data to be collected and the data to be used in the models can be better quality. This data is mainly used in production areas with sensors (temperature, humidity and so on to be used in data collection. the datasets to be created by collecting sensors) will be available both in these studies and in larger scale works and will bring a new dimension to the studies.

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