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Bazı Arpa Çeşitlerinin Kadmiyum ve NaCl Tuz Stresinde Cd Biriktirme Kapasitelerinin Belirlenmesi

Faruk Özkutlu[1], Onur Burkan[1]

[1] Ordu Üniversitesi, Ziraat Fakültesi, Toprak Bilimi ve Bitki Besleme, Ordu

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Öz

Bu araştırma, sera koşullarında saksı denemesi şeklinde yürütülmüştür. Toprakta 5 mg Cd kg^{-1} düzeyinde kirlilik oluşturulmuştur. Cd (5 ppm) ve NaCl (0 ve 3000 ppm) dozları altında yetiştirilen altı arpa bitkisinin yeşil aksam kuru madde verimi ve Cd konsantrasyonu belirlenmiştir. Cd uygulamasıyla arpa çeşitlerinin yeşil aksam kuru madde verimlerinde önemli farklılıkların olduğu saptanmıştır. Bu etki, Cd 5 ppm ve NaCl (3000 ppm) uygulamasında ise daha belirgin olarak elde edilmiş ve yaklaşık %25 oranında kuru madde verimleri azalmıştır. Çeşitler arasında en fazla kuru madde verimi Çetin 2000 çeşidinde %26.6 oranında azaldığı belirlenmiştir. Her iki stres altında yetiştirilen arpa çeşitlerinin Cd biriktirme kapasitelerinde de önemli farklılıkların olduğu tespit edilmiştir. Tuzsuz ve Cd 5 uygulamasına göre Cd 5 +NaCl uygulaması sonucunda yeşil aksamda Hilal çeşidinde 3.3 kat daha fazla Cd biriktirdiği saptanmıştır. Tuzsuz ortamda en az Cd biriktiren çeşit Hilal iken tuzlu ortamda ise en fazla Cd biriktiren çeşit ise Avcı 2002 (35.57 mg kg^{-1}) olduğu bulunmuştur. Araştırma sonuçlarında çeşitler arasındaki kuru madde ve çeşitlerin Cd biriktirme kapasiteleri istatistiksel olarak $P<0.05$ önemli olduğu saptanmıştır. Bu araştırmada, tuzun bazı yemlik arpa çeşitlerinde Cd alımını arttırdığı ortaya konulmuştur.

Anahtar Kelimeler: tuz (NaCl), kadmiyum (Cd), arpa

Determining of Cd Accumulation Capacities of Some Barley Varieties under Cadmium and NaCl Salt Stress

Abstract

This research was conducted as a pot experiment under greenhouse conditions. Soil was contaminated at a level of 5 ppm Cd. Shoot dry matter yield and Cd concentration of six barley plants grown under Cd 5 ppm and NaCl (0 and 3000 ppm) doses were determined. It was revealed that there were significant differences in shoot dry matter yields of barley cultivars with Cd treatment. This effect was more significant in Cd 5 ppm and NaCl (3000 ppm) treatments, which decreased dry matter yields by about 25%. Among the varieties, the highest dry matter yield was determined to be decreased by 26.6% in Çetin 2000 variety. There were also significant differences in Cd accumulation capacity of barley varieties grown under both stresses. It was determined that the Cd 5 + NaCl treatment accumulated 3.3 times more Cd in the green parts of Hilal cultivar as a result of Cd 5 + NaCl treatment compared to Cd 5 and no salt treatment. It was found that Hilal was the least Cd accumulating cultivar in without NaCl while the highest Cd accumulating cultivar was Avcı 2002 (35.57 mg kg^{-1}) in +NaCl treatment. In the results, it was found that dry matter yield and Cd accumulation capacity of the varieties were statistically significant at $P<0.05$ level. In this study, it was revealed that salt increased Cd uptake in some livestock feed barley varieties.

Keywords: salt (NaCl), cadmium (Cd), barley (Hordeum vulgare)

Sorumlu Yazar / Corresponding Author: Faruk Özkutlu fozkutlu@odu.edu.tr

Giriş

Tarımsal ürünler çeşitli biyotik ve abiyotik streslerin tehdidi altındadır. Abiyotik stresler arasında yer alan toprak tuzluluğu ve ağır metal stresi (Shahid vd., 2015) ciddi çevresel tehlikeleri oluşturmaktadır (Hamid vd., 2008), özellikle kurak ve yarı kurak alanlarda tuz stresi mahsul verimliliğinin azalmasına (Afzal vd., 2008, Dinler vd., 2021, Ekbic vd., 2017; Korkmaz vd., 2020) neden olmaktadır. Bitkilerde büyümedeki sınırlamalar ve verim kalitesinin bozulmasında tuzluluk önemli rol oynamaktadır. Bu nedenle çeşitli bitki türleri tuzluluk sorununa karşı savunma mekanizmaları geliştirmiştir. Tuzluluğa dayanıklılığı olan bitkilerin kökleri tuzu bünyelerine almazlar. Bu tür bitkiler yarı-geçirgen zar özelliği taşıdıklarından su moleküllerinin geçmesine olanak sağlarlar. Diğer taraftan toprakta tuzluluk yüzdesi fazlalaşıp çözünmüş durumda olduğunda bitkilerin topraktan su alımı güçleşmektedir. Bu nedenle de, toprak yapısında bozulmalar ve iyonlarda dengesizlikler oluşmaktadır. Bozulmalar sonucunda bitkiler tarafından aşırı miktarda alınan tuz, hücre fonksiyonlarında tahribatlar meydana getirmesiyle fotosentez ve solunum işlevlerinde gerilemeler olmaktadır (Rady, 2011, Uyanık vd., 2014). Toprakta yüksek tuz konsantrasyonu olduğunda Na iyonunun fazlalığı nedeniyle toprağın fiziksel yapısında bozulmalarla birlikte bitkilere fazla miktarda alınan Na iyonundan kaynaklı bitkisel ürünlerin verim ve kalitelerinde düşüşlere sebep olmaktadır (Sönmez ve Sönmez, 2007). Dünya nüfusunun artışına bağlı olarak daha fazla gıdaya erişmeyi sağlamak için verimin arttırılmasında gübrelerin yoğun olarak kullanıldığı belirlenmiştir (Korkmaz vd., 2021). Uygun olmayan aşırı gübreleme sonucunda; toprak reaksiyonunda değişimler ve iyonların dengesinde bozulmalar oluşmaktadır. Kimyasal gübrelerin gereğinden fazla kullanılmasında topraklarda kirlilik oluşmakla kalmayıp toprağın toksik maddelerce zenginleşmesini de sağlamaktadır. Daha fazla verim almak amacıyla fosforlu gübrelerin yoğun olarak kullanılmasıyla topraklara yüksek miktarda Cd girişi olabilmektedir (Kılıç ve Korkmaz, 2012). Fosfat kaya rezervlerinin çok büyük bir bölümünün bileşiminde çeşitli ağır metallere rastlamak mümkündür. Fosfatlı gübrelerin hammaddesinde genellikle düşük miktarlarda da olsa Hg, Ni, As, Cr, Pb bulunmaktadır. Bunlardan başka, fosforlu gübrelerin hammaddelerinde özellikle yer alan Cd uzun yıllar gübrelemenin sonucunda topraklarda belli miktarda birikimden sonra bitkilere yoğun olarak taşınabilmekte ve yenilebilir bitkilerden de besin zinciri vasıtasıyla insanlara geçmektedir (Çağlarırmak, 2010; Korkmaz vd., 2010; Korkmaz vd., 2017; Korkmaz vd., 2018). Sanayileşmenin artışına bağlı olarak, endüstriyel alanların çevresinde ağır metal kirlilikleri ve özellikle de Cd kirliliği önemli bir çevresel sorun teşkil etmektedir (Aydemir vd., 2022). Son 50 yıldır tarımsal alanlarda kullanılan gübreler, antroponejik ve atık çamurlarından kaynaklanan Cd'un en önemli kirletici kaynaklar arasında olduğu görülmektedir. Topraklara giriş yapan ve yüksek miktarda biriktiğinde toprakta mikrobiyal aktivitenin, toprak verimliliğinin azaldığı buna bağlı olarak da ürünlerdeki verim kayıplarının oluşmasına insanlar tarafından yüksek miktarda Cd içeren besinlerin tüketilmesiyle ciddi sağlık sorunlarına neden olabilmektedir (Buchet vd., 1990; Gill ve Tuteja, 2011). Tarımsal alanlarda genellikle Cd düşük miktarlarda olduğu Kabata-Pendias ve Pendias (1992) göre, tarımsal alanlarda dünyada Cd konsantrasyonunun 0.06-1.1 mg kg^{-1} arasında değiştiği ve ortalama olarak 0.53 mg kg^{-1} olduğu bildirilmiştir.

Tarımsal topraklarda Cd dinamiği; tekstür, hidro oksitler, serbest karbonatlar, toprağın pH, redoks durumu, organik madde içeriği gibi özellikler tarafından etkilenmektedir. Bunlardan başka, son yıllarda toprakların tuzluluk durumlarının bitkilerin Cd alımını artırdığı birçok araştırma yer almaktadır (Özkutlu, 2007; Pedro vd., 2013). Tarımsal topraklarda yüksek tuz konsantrasyonu olduğunda bitkisel ürünlerin yetiştirilmesinde verim ve kaliteleri gibi çeşitli sorunlar oluşmaktadır. Topraklarda hem tuz hem de ağır metal özellikle de Cd birlikte olduğunda bitkilerdeki stres artmaktadır. Sadece tuz stresi olduğunda kültür bitkileri tuza dayanıklılık açısından farklılar gösterebilmektedir. Tuzluluğa karşı bazı bitkiler hassas iken bazıları da tuza karşı çeşitli dayanım mekanizmaları oluşturarak dayanıklı olurlar. Örneğin, pamuk, şekerpancarı, buğday ve arpa bitkileri tuza dayanıklılıkta yüksek tolerans göstermektedir (Bayraklı, 1998). Bu araştırmada, tuz ve Cd stresi altında yetiştirilen altı arpa çeşidinin Cd biriktirme kapasiteleri araştırılmıştır.

Materyal ve Yöntem

Denemede, Ordu Üniversitesi Uygulama Arazisinden 0-20 cm derinlikten alınan toprak kullanılmıştır. Deneme, arpa yetiştiriciliğinde yaygın olarak kullanılan yemlik özellikte iki sıralı olan (Avcı 2002, Bornova 92, Bülbül, Çetin 2000, altı sıralı, Hilal ve Süleyman Bey) çeşitlerle yürütülmüştür.

Materyal

Denemede, Ordu Üniversitesi Uygulama Arazisinden 0-20 cm derinlikten alınan toprak kullanılmıştır. Denemede kullanılan toprak; tekstür (Tın), organik madde (%1.45), pH 7.42, kireç (%3.2), EC (332 µs/cm), bitkiye yarayışlı fosfor (14 ppm), potasyum (199 ppm), kalsiyum (5526 ppm), magnezyum (143 ppm) ve mikro elementlerden sodyum (50 ppm) ve DTPA da ekstrakte edilebilir demir (Fe), çinko (Zn), bakır (Cu) ve mangan (Mn) sırasıyla 7.5, 1.0, 1.9 ve 5.5 mg kg^{-1} değerlerine sahiptir. Denemede, arpa yetiştiriciliğinde yaygın olarak kullanılan yemlik özellikte iki sıralı olan (Avcı 2002, Bornova 92, Bülbül, Çetin 2000, altı sıralı, Hilal ve Süleyman Bey) çeşitler kullanılmıştır.

Yöntem

Uygulamalar Saksı Denemesinin Kurulması ve Yürütülmesi

Deneme, tesadüf parselleri deneme deseninde 3 tekrarlamalı olarak kurulmuştur. 6 numaralı plastik saksılara 4 mm elekten elenmiş 1.650 kg toprak doldurulmuştur. Saksılara temel gübreleme olarak 200 ppm N, 100 ppm P, 125 ppm K ve 1 ppm Zn uygulanmıştır. Temel gübrelemeden sonra; Cd ve NaCl etkileşimi araştırmak amacıyla (5 ppm Cd) dozu verilmiştir. Daha sonra NaCl 3000 ppm dozu iki defada eşit miktarda olacak şekilde birinci kısım tohumların ekimi ile ve çimlenme olup bitkiler 6 bitki olacak şekilde seyrelttikten sonra diğer yarısı uygulanmıştır. Bitkilerin büyümelerinde farklılıkların oluştuğu 70. gününde hasat edilmiştir.

Bitki Analizleri

Hasat edilen bitki örnekleri etüvde kurutulup ağırlıkları alınmış ve öğütülmüştür. Öğütülen örneklerinden 0.25 g tartılarak 4 ml HNO3 (% 65'lik), 2 ml H2O2 (% 30'luk) ve 2 ml saf su içeren bir karışımda mikro dalgada yakılmıştır. Süzükler soğuduktan sonra whatman filtre kağıdından süzülerek Cd konsantrasyonu ICP-OES cihazıyla ölçülmüştür. İstatistik analizleri SPSS programında yapılmıştır.

Bulgular ve Tartışma

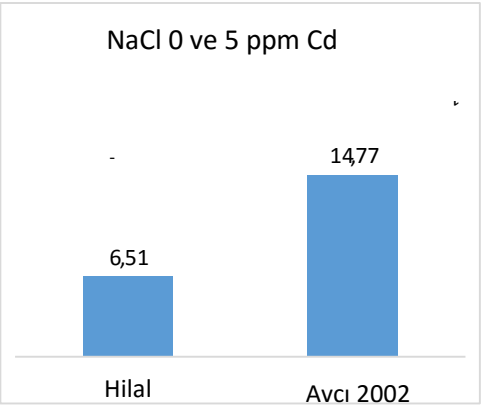
Kadmiyum (Cd) ileTuz (NaCl) İnteraksiyonu

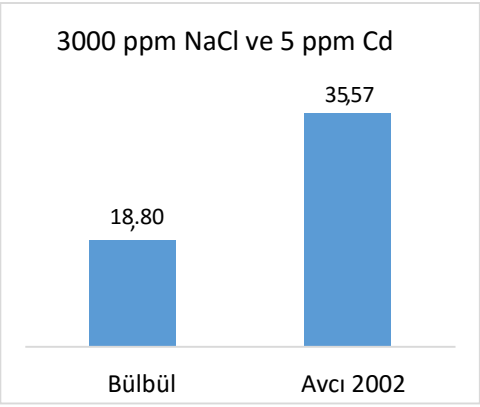
5 ppm Cd topraklara ilave edilerek kirlilik oluşturulmuş ve NaCl 0 ve NaCl ppm dozları altında yetiştirilen yemlik özellikteki altı arpa çeşitlerinin yeşil aksam kuru madde verimleri ve Cd konsantrasyonları belirlenmiştir. Elde edilen bulgulara göre, çeşitlerin kuru madde verimlerinde önemli farklılıkların olduğu saptanmıştır. Beklenildiği gibi NaCl 3000 ppm uygulamasında bütün çeşitlerin kuru madde verimleri azalmıştır. Bütün çeşitlerde Cd 5 -NaCl 0 dozlarına göre, NaCl tuzunun 3000 ppm uygulanmasıyla yaklaşık olarak %25 oranında kuru madde verimlerinde düşüş olduğu bulunmuştur. Kuru madde veriminin en fazla azaldığı Çetin 2000 çeşidinde %26.6 düzeyinde olduğu tespit edilmiştir (Tablo 1).

Tablo 1. 5 ppm Cd'la Kirlilik Oluşturulan Toprağa NaCl Tuzunun (0 ve 3000 ppm) Doz Uygulamaları Altında Yetiştirilen Arpa Çeşitlerinin Yeşil Aksam Kuru Madde Verimi ve Cd Konsantrasyonları

Arpa Çeşitleri	NaCl	Yeşil Aksam Kuru Madde Verimi (mg bitki^{-1})	Yeşil Aksam Cd Konsantrasyonu (ppm)
	Uygulamalar	Cd 5	
Avcı 2002	0	466	14,77 e
	3000	347	35,57 a
	Ortalama	407 D	25,17 A
Bornova 92	0	591	6,90 g
	3000	451	20,66 c-d
	Ortalama	521 A	13,78 D
Bülbül	0	509	8,38 f-g
	3000	383	18,80 d
	Ortalama	446 C	13,54 D
Çetin 2000	0	461	13,88 e
	3000	339	28,13 b
	Ortalama	400 D	21,01 B
Hilal	0	564	6,51 g
	3000	416	21,61 c
	Ortalama	490 B	14,06 D
Süleyman Bey	0	570	9,32 f
	3000	437	21,87 c
	Ortalama	504 B	15,59 C
Ortalama	0	527 A	9,94 B
	3000	396 B	24,44 A
		LSD(%5)$_{çeşit}$: 16,67522 LSD(%5)$_{tuz}$: 9,62743 LSD(%5)$_{çeşitxtuz}$: 22,92522	LSD(%5)$_{çeşit}$:1,44155 LSD(%5)$_{tuz}$: 0,83227 LSD(%5)$_{çeşitxtuz}$:2,03866

5 ppm Cd düzeyinde topraklara ilave edilerek kirlilik oluşturulmuş ve NaCl 0 ve 3000 ppm NaCl tuzunun uygulanmasıyla çeşitler arasında Cd'a dayanıklılık kapasiteleri yönünden önemli farklılıkların olduğu saptanmıştır. 5 ppm Cd ve -NaCl (tuzsuz) uygulamasında Hilal çeşidi en az Cd biriktiren çeşit olup Cd konsantrasyonu 6.51 ppm düzeyinde iken en yüksek Cd konsantrasyonu 14.77 ppm ile Avcı 2002 çeşidinde olmuştur (Şekil 1).





Şekil 1. Tuz'suz Cd 5 mg kg^{-1} ve NaCl 3000 Cd 5 mg kg^{-1} Uygulaması Altında Yetiştirilen En Düşük ve En Yüksek Cd Konsantrasyonuna Sahip Çeşitler (mg kg^{-1})

5 ppm Cd ve tuzsuz (NaCl 0) uygulamasına göre, 3000 ppm NaCl tuz verilince bitkilerin Cd konsantrasyonlarının 2.02 ile 3.30 kat aralığında arttığı saptanmıştır. Şekil 1'de görüldüğü gibi 3000 ppm NaCl tuz uygulamasında en düşük Cd konsantrasyonu Bülbül çeşidinde olmasına karşın en fazla Cd konsantrasyonu ise 35.57 ppm olarak Avcı 2002 çeşidinde olduğu tespit edilmiştir. Bu sonuç göstermektedir ki çeşitler arasında Cd konsantrasyonu yönünden geniş bir varyasyon bulunmaktadır. Bu durum muhtemelen Cd'un Cl^- anyonu ile yapılan kompleksler neticesinde katyon değiştirici yüzeylere bağlanması azalmakta ve böylelikle Cd alımına dayanıksız olan bitkilerde alınma şansının daha fazla olduğu düşünülmektedir. (Smolders ve McLaughlin, 1996; Özkutlu vd., 2007; Rady, 2011; Özkutlu ve Kara 2019). Tuzluluk, en önemli abiyotik streslerden biri olup bitkisel üretimde verimliliği sınırlamaktadır. Topraktaki fazla tuzlar tek başına veya başka kombinasyon oluşturarak bitkilerde su kaybına, iyon dengesizliğine ve spesifik iyon toksisitesine neden olmaktadır (Serrano vd., 1999). Tuzun bitkilerde Cd alımını arttırdığına yönelik birçok araştırma bulunmaktadır. Örneğin, çeşitli araştırmacılara tarafından tuzlu koşullarda buğdayda Cd daha taşındığı (Rizwan vd., 2016; Özkutlu ve Kara 2019) arpada ise Smykalova ve Zamecnikova (2003) tarafından bildirildiğine göre, Cd ve tuz stresi altında yetiştirilen bitkilerde kontrole göre daha fazla Cd taşındığı açıklanmıştır. Huang vd., 2007 tarafından, su kültürü ortamında Cd ve tuz stresi altında yetiştirilen 4 arpa genotipinin Cd konsantrasyonları bakımından benzer sonuçlar elde edildiği bildirilmiştir. Literatürdeki bu sonuçlarla tarafımızdan yapılan araştırmanın sonuçlarıyla uyumlu olduğu tespit edilmiştir.

Sonuç ve Öneriler

Topraklarda Cd kirliliği sürekli artmakta ve önemli çevresel bir tehdit oluşturmaktadır. Toprak tuzluluğunun arpa bitkilerinde Cd birikimini etkileyen önemli bir faktör olduğu saptanmıştır. Tuz toleransı yüksek olan arpa çeşitlerinin Cd biriktirme kapasitelerinin önemli oranda farklılıklar oluşturduğu ve tuzun etkisiyle de yeşil aksama 3.3 kat daha fazla Cd birikmesine neden olduğu saptanmıştır. Bitkisel ürünlerde Cd birikimini arttıran ve azaltan faktörlerin belirlenmesi insan sağlığı açısından önem taşımaktadır. Bu nedenle, tuzluluk ve Cd stresi ile birlikte olduğunda arpa çeşitlerinde verim ve kalitede bozulmalar oluşmaktadır. Özellikle tuzluluğun yoğun olduğu bölgelerde topraklarda Cd kirlilik boyutu tanımlanmalıdır. Hem Cd kirliliği hem de tuzluluk stresine dayanıklı olan çeşitlerin araştırılıp elde edilmesi gerekmektedir.

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Yazarlar herhangi bir çıkar çatışması olmadığını belirtmektedir.

ORCID

Faruk Özkutlu https://orcid.org/0000-0002-8651-3346

Onur Burkan https://orcid.org/0009-0003-8249-201X

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Atıksu Borularında Hesaplamalı Akışkanlar Dinamiği Probleminin Karakteristikler Yöntemi ile Doğrulanması

Esin Acar[1]

[1]Artvin Çoruh Üniversitesi, Borçka Acarlar MYO, İnşaat Bölümü, Artvin

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Öz

Bu çalışmada kararsız akış koşulları altında yumurta kesitli atık su borularında hesaplamalı akışkanlar dinamiği (CFD) programı kullanılarak oluşturulan akış sonuçlarının, karakteristikler yöntemi kullanılarak karşılaştırılması ve istatistiksel analizler ile doğrulaması yapılmıştır. Yumurta kesitli atık su boruları 3 faz (katı, sıvı ve gaz) olarak incelenmiş olup, zamana bağlı değişen akış hızlarına bağlı CFD programı kullanılarak işletme çalışması yapılmış, ortaya çıkan hız ve piyezometre yükseklikleri verileri programdan alınmıştır. Karakteristikler yöntemi için serbest yüzeyli akış boru hattı hesaplama esaslarına göre başlangıç koşulu olarak t=0 zamanı, boru içerisindeki akışın kararlı akış olması şartına bağlı olarak çalışma yapılmıştır. Çalışmada t=156s'lik zaman diliminde 6s'lik verilerden yararlanılarak elde edilen CFD çıktıları ve karakteristikler yöntemi ile hesaplanan sonuçlar oluşturulmuştur. Elde edilen veriler karşılaştırılarak istatistiksel analizler yapılmış ve uyumlu olduğu görülmüştür. Böylece analitik ve nümerik bir çalışmanın karşılaştırılması yapılmış, istatistiksel analizler ile desteklenmiştir.

Anahtar Kelimeler: hesaplamalı akışkanlar dinamiği (CFD), karakteristikler yöntemi (MOC), kararsız akış, çok fazlı akış, yumurta kesitli boru

Verification of Computational Fluid Dynamics Problem in Wastewater Pipes by Characteristics Method

Abstract

In this study, the flow results generated using the computational fluid dynamics (CFD) program in egg-section wastewater pipes under unstable flow conditions were compared using the characteristics method and verified with statistical analysis. Egg-section wastewater pipes were examined as 3 phases (solid, liquid and gas), and the operation study was carried out using the CFD program based on time-varying flow rates, and the resulting velocity and piezometer height data were taken from the program. For the characteristics method, the study was carried out based on the free-surface flow pipeline calculation principles, with t = 0 time as the initial condition and the flow in the pipe being a stable flow. In the study, CFD outputs obtained using 6 s of data in a time period of t = 156 s and results calculated with the characteristics method were created. Statistical analyzes were performed by comparing the data obtained and it was found that they were compatible. Thus, a comparison of an analytical and numerical study was made and supported by statistical analysis.

Keywords: computational fluid dynamics (CFD), method of characteristics (MOC), unsteady flow, multi phase flow, egg shaped pipe

Sorumlu Yazar / Corresponding Author: Esin Acar esin.acar@artvin.edu.tr

Giriş

Çevremizde yer alan birçok akış zamana bağlı değişen akış koşullarını taşımaktadır. Bu sebeple kararsız akış koşullarının incelenmesi ve değerlendirilebilmesi amacıyla hesaplamalı akışkanlar dinamiğinden yararlanılmaktadır. Bu programlar sayesinde çözülmesi zor denklemlerin çözümü ve akışkan hareketlerinin incelenebilmesi sağlanmaktadır. Bilgisayar destekli bu programlar birçok akışkan dinamiği problemlerini çözebilmektedir.

Çalışmada kullanılan yumurta kesitli atık su borusu çok fazlı akış olarak tasarlanmıştır. Bu fazlar katı, sıvı ve gaz olup zamana bağlı değişen katı madde ve sıvı hızları CFD programına girilerek t=156s'lik bir zaman diliminde çalışılmıştır. Karakteristikler yöntemi ile çalışmanın doğrulanması amaçlandığı için öncelikle kararlı akış durumda t=0 anında, serbest yüzeyli akış koşulları dikkate alınarak 600mmx900mm ebatlarındaki yumurta kesitli, 1/1000 eğimli, 20 m uzunluğunda giriş ve çıkış menhollü bir boru hattı oluşturulmuştur. Zamana bağlı olarak 6s'de bir boru boyunca 5 m lik kesitlerde CFD programından hız ve piyezometre yükseklikleri alınmıştır. Karakteristikler yöntemi ile boru hattına ait ilk ve son kesitteki akışkan hızı ve piyezometre yükseklikleri CFD programı verilerinden çekilmiştir. Daha sonra serbest yüzeyli akış koşullarındaki MOC hesap yöntemi esaslarına göre t=6s'de bir hız ve piyezometre yükseklikleri elle hesap ve Excel yardımıyla yapılmıştır.

Tezcan vd. (1998) çalışmalarında, karmaşık boru sistemlerinin karakteristikler yöntemini kullanarak kararsız akış analizini yapmıştır. Aşırı talep ve vana, pompa gibi cihazların aniden açılıp kapanması ile boru sistemleri kararsızlıkların oluşmasına neden olduğunu belirtmiştir. Bu sebeple boru sisteminin hidrolik analizi artık yalnızca kararlı durumda gerçekleşmediği için, kararsız akış analizi ile çalışma yapılmıştır.

Swaffield (1982) çalışmasında, kısmen doldurulmuş kararsız boru akışında akış zayıflama mekanizması sunulmuş ve yer altı drenaj sistemlerinin tasarımıyla ilgisi olduğu gösterilmiştir. Kısmen dolu bir boruda kararsız akışı tanımlayan denklemler türetilmiş ve karakteristikler yöntemiyle çözümlenebildiği gösterilmiştir. Uzun bir drenaj borusu boyunca akış derinliğini, hızını ve dalga hızını çeşitli boru eğimleri, çapları ve pürüzlülük katsayılarında tahmin etmeye yönelik bir yöntem olan bu teknik, dijital bir bilgisayarda çalıştırılan bir dizi simülasyon için sayısal örnekler aracılığıyla test edilmiştir.

Salih (2016) çalışmasında, Karakteristikler yöntemi, hiperbolik kısmi diferansiyel denklemleri (PDE) çözmeye yönelik bir teknik olduğunu belirtmiştir. Tipik olarak bu yöntem birinci dereceden denklemlere uygulanır, ancak herhangi bir hiperbolik tip PDE için de geçerlidir. Yöntem, karakteristik eğriler olarak adlandırılan ve PDE'nin bir sıradan diferansiyel denklemler (ODE) ailesi haline geldiği özel eğrilerin belirlenmesini içerir. ODE'ler bulunduktan sonra, ODE'nin çözümlerini elde etmek için karakteristik eğriler boyunca çözülebilir ve daha sonra ODE'nin çözümleri orijinal PDE'nin çözümüyle ilişkilendirilebilir olduğunu belirtmiştir.

Kumar (2020), Karakteristikler metodu temel olarak doğrusal olmayan birleşik kısmi diferansiyel denklemi, karakteristik yönler olarak bilinen belirli yönler boyunca daha basit, ayrıştırılmış denklemlere indirgemek için kullanılan matematiksel bir yöntemdir. Süpersonik akışları içeren problemlerde, kütle, momentum ve enerji korunumunun kombinasyonu, böyle bir doğrusal olmayan, kısmi, birleşik diferansiyel denklemi verir. Bu denklemin ayrıştırılması, birleştirilmiş terimin değişkenleri belirsizdir. Bu, biri karakteristik eğrilerin yönüne karşılık gelen ve diğeri uyumluluk koşullarını temsil eden iki denklem seti verdiğini belirtmiştir.

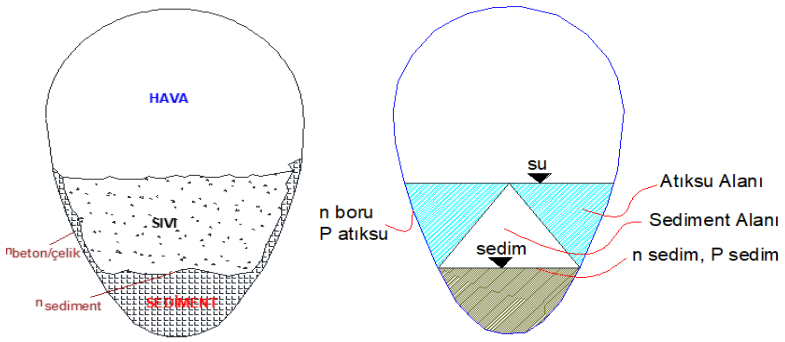
Materyal ve Yöntem

Çalışmada kullanılan yöntemler; $n_{kompozit}$ pürüzlülük hesabı, karakteristikler yöntemi ile CFD programı olan Star CCM^{+} programıdır. Bu çalışma ile hem analitik hem de sayısal hesap yöntemlerinin kullanılması sağlanmıştır.

Manning Kompozit Pürüzlülük Katsayı ($n_{kompozit}$) Hesabı

Çalışmada boru hattına gelen akımlar zamana bağlı olarak değiştiği için boru tabanında sediment birikimi oluşmaktadır. Bu sebeple belirlenen kesitlerdeki sedimentten kaynaklı yumurta kesitin pürüzlülük değerleri değişeceğinden dolayı, öncelikle 6s'de bir kesitlerdeki $n_{kompozit}$ pürüzlülük değerleri hesaplanmıştır. 3 fazlı akış ortamında, boru hattının tabanında bir sediment birikimi söz konusudur.

Akış ortamındaki hız dağılıma benzetilen bir hız dağılımı Açık Kanal (Nehir) Akışı (2008) esas alınmış ve farklı yüzey pürüzlülüklerinden kaynaklanan Manning pürüzlülük katsayısı, kompozit olarak hız dağılımı ve hızların egemen oldukları yüzeylerin (boru materyali ya da taban sediment materyali) pürüzlülüklerine eşitlik (1)'e göre hesaplanmıştır (Şekil 1) (Acar, 2023).



(a) (b)

Şekil 1. (a) Yumurta Kesit 3 Faz Gösterimi, (b) Hidrolik Yarıçapın Belirlenmesinde Islak Çevre-Islak Alan Paylaşımı Kabulünün Gösterimi

Her gözlem kesitte ve değişen zaman aralıklarında $n_{kompozit}$ pürüzlülük katsayıları, kesit alanı içinde sediment birikiminin yüksekliği-sediment alanı dikkate alınarak eşitlik (1) bağıntısıyla hesaplanma yoluna gidilmiştir.

$$n_{kompozit} = \frac{\left(\sum n_i^{\frac{3}{2}} P_i\right)^{\frac{2}{3}}}{P^{\frac{2}{3}}} \tag{1}$$

Eş hız eğrilerine ve eğrilerin ait oldukları yüzeye paralel seyirleri göz önüne alınarak bir kabul dâhilinde kompozit pürüzlülüğün gerektirdiği ıslak çevrelere (P_i) ve bölünmüş alana karşılık gelen yüzey pürüzlülüğüne (n_i) dayalı $n_{kompozit}$ katsayısı hesaplanmıştır.

Acar (2023), Eşdeğer pürüzlülük değeri yumurta kesitli boru hattındaki pürüzlülük değerini tanımlamak amacı ile kullanılmaktadır. Bu sebeple sediment tanımlaması yaparken girilen eşdeğer pürüzlülük değeri problemin doğru tanımlanabilmesinde önemli bir etkendir. STAR CCM$^+$ programında da bu değer tanımlanabilmektedir.

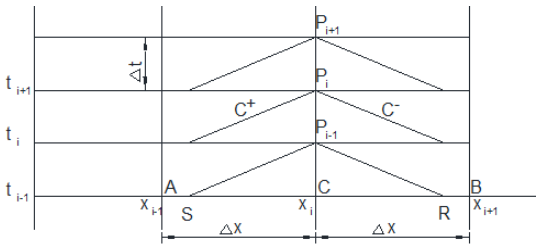
Regueiro-Picallo (2016), Sayısal modeldeki pürüzlülük k_s, Strickler denkleminde yer alan ($n_{kompozit}=k_s^{1/6}/25$) bağıntısına uygun olarak $n_{kompozit}$'in bir fonksiyonu olacak biçimde tahmin etmiştir. Çalışmada 6 s'de bir olmak üzere Kesit 0-5-10-15-20 'ye ait hesaplanan $n_{kompozit}$ değerleri Tablo 1'de verilmiştir.

Tablo 1. Serbest Yüzeyli Boru Akışına ait $n_{kompozit}$ değerleri

t(s)	Kesit 0 n_{komp}	Kesit 5 n_{komp}	Kesit 10 n_{komp}	Kesit 15 n_{komp}	Kesit 20 n_{komp}
0	0.028	0.028	0.028	0.028	0.026
6	0.027	0.033	0.031	0.031	0.027
12	0.026	0.033	0.027	0.032	0.029
18	0.028	0.033	0.030	0.032	0.029
24	0.027	0.033	0.026	0.032	0.029
30	0.027	0.028	0.026	0.029	0.029
36	0.026	0.029	0.026	0.028	0.031
42	0.025	0.029	0.029	0.030	0.029
48	0.025	0.030	0.026	0.028	0.033
54	0.025	0.026	0.027	0.028	0.029
60	0.025	0.027	0.026	0.028	0.028
66	0.025	0.024	0.026	0.030	0.028
72	0.030	0.026	0.025	0.027	0.027
78	0.025	0.024	0.025	0.027	0.029
84	0.026	0.028	0.025	0.026	0.028
90	0.025	0.026	0.025	0.026	0.028
96	0.026	0.028	0.025	0.026	0.028
102	0.026	0.026	0.025	0.026	0.028
108	0.028	0.028	0.025	0.025	0.028
114	0.028	0.027	0.025	0.024	0.026
120	0.029	0.033	0.025	0.024	0.026
126	0.031	0.029	0.026	0.024	0.025
132	0.032	0.032	0.028	0.025	0.027
138	0.034	0.032	0.028	0.025	0.024
144	0.034	0.027	0.026	0.026	0.026
150	0.026	0.032	0.030	0.026	0.025
156	0.026	0.030	0.028	0.029	0.026

Karakteristikler Yöntemi

Bu yöntem "gerek karmaşık boru sistemlerinde, gerekse kararsız akışın hidrolik analizinde, çoğu şartnamede ve hidrolik hesaplamalarda kararlı akış durum koşullarının dikkate alınarak hesaplanmaktadır. Yarı-kararsız akış olarak her akış diliminde (genellikle saat bazında) farklılaşan akış hızların ortalaması alınarak kararlı çözülmektedir. Ancak bilinmektedir ki baz zaman dilimi içinde akış hızı kararsız bir değişim göstermektedir" (Acar, 2023). Şekil 2'de MOC hesabına ait şema verilmiştir.



Şekil 2. Serbest Yüzeyli MOC Hesap Şeması

Serbest yüzeyli akış olması durumunda kullanılan bu sonlu farklar analizinde V_R, c_R hızlar (2) ve (3), h_R ve h_S su derinlikleri (4) ve (5) ve θ (6), V_S, C_S (7) ve (8) hızları, öncelikle hesaplanacaktır (Swaffield, 1982). Burada c değeri ise courant sayısı olup yüzeysel dalga yayılma hızı değeri (9), Δt zaman aralığı (10), $\frac{dt}{dx}$ (11) ve S kanal taban eğimi (12) eşitlikleriyle verilmektedir.

$$V_R = \frac{V_C+\theta(-V_C c_A+c_C V_A)}{1+\theta(V_C-V_A+c_C-c_A)} \tag{2}$$

$$c_R = \frac{c_C+(1-V_R\theta)+c_A V_R\theta)}{1+c_C\theta-c_A\theta} \tag{3}$$

$$h_R = h_C - (h_C - h_A)\big(\theta(V_R + c_R)\big) \tag{4}$$

$$h_S = h_C + \theta(V_S - c_S)(h_C - h_B) \tag{5}$$

$$\theta = \Delta t/\Delta x \tag{6}$$

$$V_S = \frac{V_C-\theta(V_C c_B+c_C V_B)}{1-\theta(V_C-V_B-c_C+c_B)} \tag{7}$$

$$c_S = \frac{c_C+V_S\theta(c_C-c_B)}{1+\theta(c_C-c_B)} \tag{8}$$

$$c = \sqrt{\frac{gA}{T}} \tag{9}$$

$$\Delta t = \frac{\Delta x}{(V+c)_{max}} \tag{10}$$

$$\frac{dt}{dx} = \frac{1}{V\mp c} \tag{11}$$

$$S = \frac{n^2V^2}{R^{\frac{4}{3}}} \tag{12}$$

Bu çalışmada, MOC hesabı yöntem gereği olarak başlangıç koşulu da t=0 zamanında boru akışının kararlı akış olması gerekmektedir. Bu sebeple çalışmada t=0 anı kararlı akış kabulünden sonra hesaplamalara başlanmıştır.

Star CCM⁺ CFD Programı

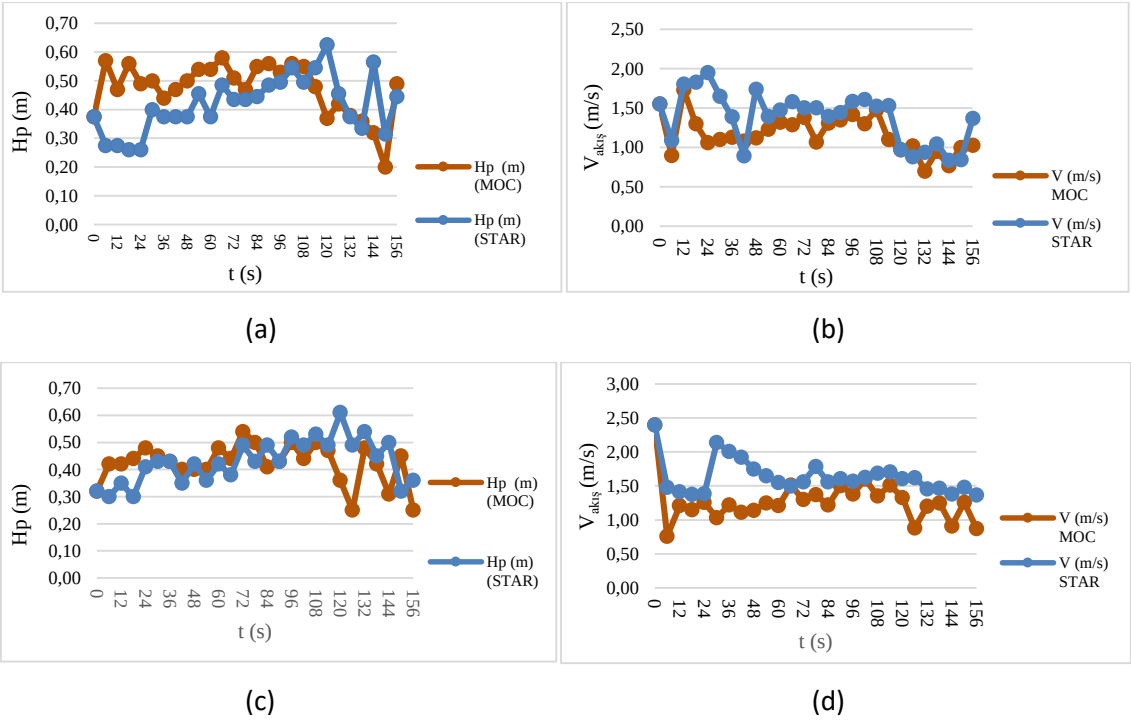
Star CCM⁺ programı hesaplamalı akışkanlar dinamiği probleminin çözümlerinde kullanılan nümerik analiz programıdır. Sonlu hacimler metodu kullanılarak modellenen ağ yapısı ile akış denklemlerinin çözümünü gerçekleştiren nümerik çözüm yöntemidir. Program birçok alanda kullanım alanı sunan akışkanlar dinamiği birden fazla faz çalışmalarında birbiri ile karışmayan akış prensiplerine dayanarak çözümlemeler yapmaktadır.

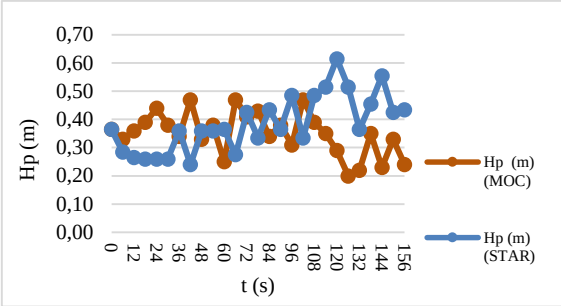
Star CCM⁺, tek bir entegre paket içerisinde en kapsamlı mühendislik fiziği simülasyonunu sağlar. Star CCM⁺ yalnızca CFD çözücüsü değildir; akış (sıvıların veya katıların), ısı transferi ve stresi içeren sorunların çözümüne yönelik bütün bir mühendislik sürecidir. Çok çeşitli modelleme ihtiyaçlarını karşılayabilecek güçlü bir paket oluşturmak için bir araya gelen bir dizi entegre bileşen sağlar (Rajak v.d., 2018). Üç boyutlu modellerde hassas çözüm için sonlu eleman sayısı çok fazla artacağından çözüm zamanı ve zorluğu da çok fazla artmaktadır. Çok fazlı ve serbest yüzeyli akımlar gibi problemlerin sayısal analizlerinin yapılabilmesi için yazılım şirketleri Çok-Fazlı Model (Multi-phase Model), Akışkan Hacmi (VOF- Volume of Fluid) modeli gibi CFD modelleri geliştirmiştir (Aydın, 2005).

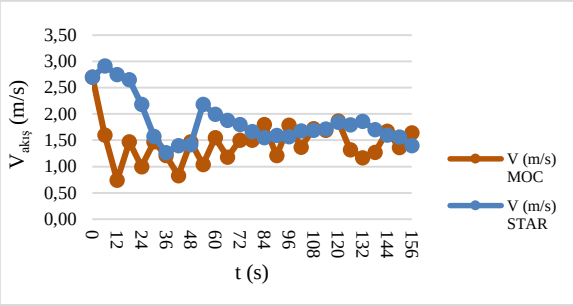
Bulgular ve Tartışma

Star CCM⁺ programı sonuçlarının doğrulanması için serbest yüzeyli boru hattında 3 fazlı akış sonuçlarının karakteristikler yöntemi ile karşılaştırılmıştır. Karakteristikler yöntemi hesap esasları gereği başlangıç koşulu olarak öncelikle kararlı duruma göre giriş ve çıkış kısmi dolu durumları Star CCM⁺ programında oluşturulmuştur. Sonra zamana bağlı değişen hız değerleri programa input verileri olarak girilerek t=156s çalışılmış, her 5 m de bir akış yükseklikleri ve hız değerleri programdan alınmıştır. Her kesitte farklılık gösteren sediment ve akış yüksekliklerine göre kompozit manning ($n_{kompozit}$) hesaplanmıştır.

Serbest yüzey akışlı karakteristikler yöntemi çalışması ile 6s'de bir hesaplanan H_p (piyezometre yüksekliği) ve $V_{akış}$ (akış hızı) oluşturulmuştur. Daha sonra 6s'de bir her 5 m'de Star CCM⁺ ve karakteristikler yöntemi ile hesaplanan değerlerler karşılaştırılmıştır (Şekil 3). MOC hesaplamalarında sedimentsiz temiz su akışı yer almış olup, boru tabanında biriken sedimentin boru tabanı kotu olduğu kabulüne göre çalışma yapılmıştır.



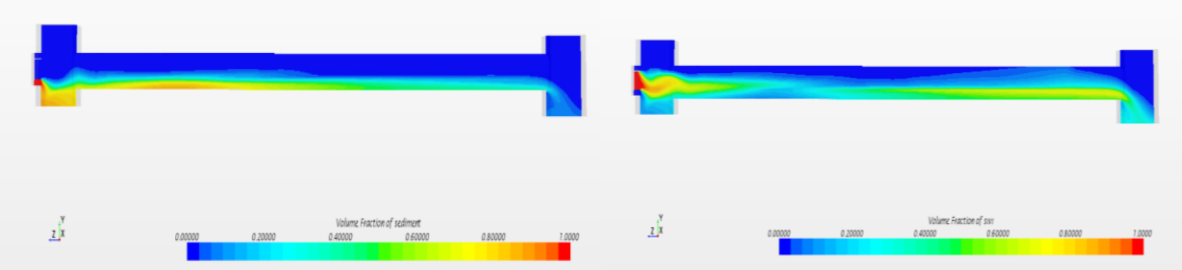




(e) (f)

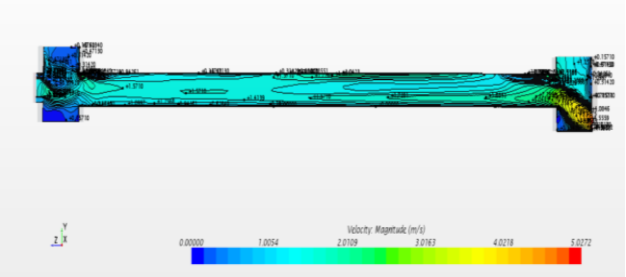
Şekil 3. MOC-Star CCM$^+$ H_p ve V Karşılaştırma Grafikleri (a) (b) Kesit 5, (c) (d) Kesit 10, (e) (f) Kesit 15

Star CCM$^+$ ve MOC karşılaştırma çalışmasına ait örnek sediment birikimi Şekil 4 (a)'da, akışkan görünümü Şekil 4 (b)'de ve hız dağılımları boy kesiti ise Şekil 5'te verilmiştir.



(a) (b)

Şekil 4. (a) Sediment Birikimi, (b) Akışkan Görünümü



Şekil 5. Karşılaştırma Çalışması Hız Dağılımları

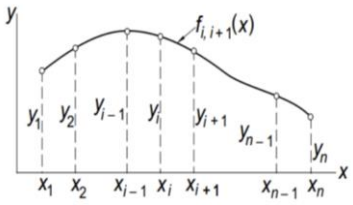
Yapılan hesaplamalara göre hem MOC hem de Star CCM$^+$ işletme sonuçlarına göre H_p, $V_{akış}$ ve Q debi değerleri Kesit 5-10-15 için Tablo 2'de verilmiştir. Bu veriler Star CCM$^+$ ve MOC çalışmalarının t=0'dan başlayarak t=156s'ye kadar olmak üzere 6s'de bir değişimlerini göstermektedir. Böylece kararsız akış koşullarının boru hattı boyunca kısa sürelerdeki değişimlerini de görmemize olanak sağlamıştır.

Tablo 2. Kesit 5-10-15 MOC- Star CCM+ karşılaştırma Tablosu

Kesit 5						Kesit 10						Kesit 15					
H_p STAR m	H_p MOC m	V MOC m s^{-1}	V STAR m s^{-1}	Q MOC m^3 s^{-1}	Q STAR m^3 s^{-1}	H_p STAR m	H_p MOC m	V MOC m s^{-1}	V STAR m s^{-1}	Q MOC m^3 s^{-1}	Q STAR m^3 s^{-1}	H_p STAR m	H_p MOC m	V MOC m s^{-1}	V STAR m s^{-1}	Q MOC m^3 s^{-1}	Q STAR m^3 s^{-1}
0.38	0.38	1.55	1.55	0.09	0.09	0.32	0.32	2.40	2.40	0.06	0.06	0.37	0.37	2.70	2.70	0.16	0.16
0.28	0.57	0.90	1.09	0.16	0.01	0.30	0.42	0.76	1.48	0.07	0.03	0.29	0.33	1.60	2.91	0.08	0.05
0.28	0.47	1.73	1.80	0.20	0.01	0.35	0.42	1.21	1.41	0.11	0.07	0.27	0.36	0.74	2.75	0.04	0.03
0.26	0.56	1.30	1.83	0.22	0.01	0.30	0.44	1.15	1.37	0.12	0.10	0.26	0.39	1.47	2.65	0.12	0.04
0.26	0.49	1.06	1.95	0.13	0.01	0.41	0.48	1.26	1.38	0.16	0.12	0.26	0.44	1.00	2.18	0.11	0.02
0.40	0.50	1.10	1.65	0.16	0.13	0.43	0.45	1.03	2.14	0.11	0.21	0.26	0.38	1.47	1.57	0.13	0.04
0.38	0.44	1.13	1.39	0.11	0.07	0.43	0.43	1.22	2.00	0.12	0.20	0.36	0.34	1.21	1.27	0.06	0.08
0.38	0.47	1.08	0.89	0.12	0.05	0.35	0.40	1.11	1.92	0.09	0.10	0.24	0.47	0.83	1.40	0.12	0.04
0.38	0.50	1.12	1.74	0.14	0.09	0.42	0.40	1.14	1.75	0.10	0.15	0.36	0.33	1.47	1.42	0.08	0.08
0.46	0.54	1.23	1.39	0.21	0.11	0.36	0.40	1.25	1.65	0.12	0.12	0.36	0.38	1.04	2.18	0.33	0.15
0.38	0.54	1.32	1.47	0.23	0.10	0.42	0.48	1.21	1.55	0.17	0.17	0.37	0.25	1.55	1.99	0.02	0.14
0.49	0.58	1.29	1.58	0.29	0.24	0.38	0.44	1.51	1.50	0.19	0.14	0.28	0.47	1.18	1.88	0.16	0.06
0.44	0.51	1.38	1.50	0.21	0.15	0.49	0.54	1.30	1.56	0.22	0.21	0.43	0.41	1.50	1.80	0.15	0.18
0.44	0.47	1.07	1.50	0.17	0.20	0.43	0.50	1.37	1.78	0.23	0.22	0.34	0.43	1.50	1.67	0.18	0.12
0.45	0.55	1.31	1.39	0.39	0.13	0.49	0.41	1.22	1.56	0.12	0.21	0.44	0.34	1.80	1.55	0.11	0.17
0.49	0.56	1.35	1.44	0.25	0.18	0.43	0.43	1.50	1.61	0.21	0.21	0.37	0.38	1.21	1.59	0.13	0.15
0.50	0.53	1.42	1.58	0.19	0.17	0.52	0.50	1.38	1.57	0.21	0.24	0.49	0.31	1.79	1.57	0.08	0.21
0.55	0.56	1.30	1.61	0.22	0.22	0.49	0.44	1.60	1.62	0.21	0.25	0.34	0.47	1.37	1.68	0.21	0.13
0.50	0.55	1.48	1.52	0.19	0.13	0.53	0.50	1.35	1.68	0.19	0.25	0.49	0.39	1.72	1.69	0.16	0.25
0.55	0.48	1.10	1.53	0.12	0.19	0.49	0.47	1.51	1.71	0.10	0.27	0.52	0.35	1.69	1.71	0.14	0.31
0.63	0.37	0.97	0.97	0.04	0.01	0.61	0.36	1.33	1.61	0.04	0.27	0.62	0.29	1.87	1.84	0.08	0.40
0.46	0.42	1.02	0.88	0.07	0.06	0.49	0.25	0.88	1.62	0.01	0.20	0.52	0.20	1.32	1.80	0.01	0.32
0.38	0.38	0.70	0.94	0.02	0.02	0.54	0.48	1.20	1.46	0.09	0.15	0.37	0.22	1.17	1.86	0.05	0.20
0.34	0.36	0.95	1.04	0.04	0.02	0.45	0.42	1.25	1.46	0.10	0.13	0.46	0.35	1.27	1.70	0.10	0.22
0.57	0.32	0.77	0.84	0.01	0.12	0.50	0.31	0.91	1.38	0.01	0.11	0.56	0.23	1.67	1.60	0.02	0.25
0.32	0.20	1.00	0.85	0.01	0.02	0.32	0.45	1.26	1.48	0.15	0.05	0.43	0.33	1.36	1.56	0.09	0.17
0.45	0.49	1.03	1.37	0.09	0.07	0.36	0.25	0.87	1.36	0.01	0.04	0.44	0.24	1.64	1.40	0.02	0.10

Hesaplanan $V_{akış}$ ve H_p değerlerinin boru boyunca değişimlerinin izlenebilmesi amacıyla kübik spline grafiklerinin çizilmesi amaçlanmıştır. Bu çalışma her 6 s'de bir olmak üzere 5 farklı kesitte uygulanmıştır.

Kübik spline fonksiyonları kesin veri noktaları arasındaki ara değerleri tahmin etmek için kullanılmaktadır. Önce verilen veri noktalarından tam olarak geçen bir fonksiyon uydurulmakta ve daha sonra bu fonksiyonlar kullanarak ara değerler değerlendirilmektedir (Zorşahin, 2009). Kübik spline hesap esasına dayalı grafik Şekil 6'da verilmiştir.

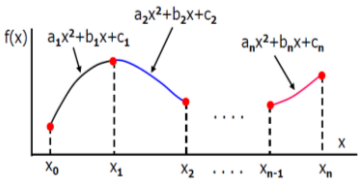


Şekil 6. Kübik Spline Hesap Grafiği (Kiusalaas, 2005).

Kübik spline hesap esaslarına ait eşitlik (13) (Numerical Interpolation, 2008);

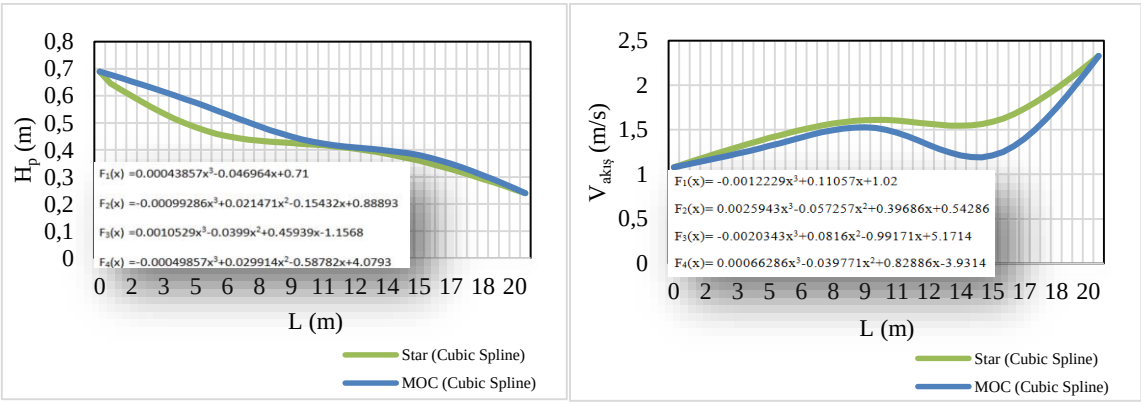
$$f_{i,i+1}(x) = \frac{k_i}{6}\left[\frac{(x-x_{i+1})^3}{x_i-x_{i+1}} - (x-x_{i+1})(x_i-x_{i+1})\right] - \frac{k_{i+1}}{6}\left[\frac{(x-x_i)^3}{x_i-x_{i+1}} - (x-x_i)(x_i-x_{i+1})\right] + \frac{y_i(x-x_{i+1})-y_{i+1}(x-x_i)}{x_i-x_{i+1}} \quad (13)$$

Kübik spline fonksiyonun grafiksel gösterimi Şekil 7'de verilmiştir.



Şekil 7. Spline Fonksiyon Grafiği

MOC ve Star CCM⁺ ile hesaplanan piyezometre yükseklikleri ile akış hızlarına ait Star CCM⁺ programından elde edilen veriler kullanılarak kübik spline fonksiyonları grafikleri oluşturulmuş ve 5 m'de bir fonksiyon oluşturulan denklemleri verilmiştir. Her 6 s'de bu grafikler yapılmış olup burada sadece t=90s için, H_p-L, $V_{akış}$-L grafikleri Şekil 8'de verilmiştir.



(a) (b)

Şekil 8. (a) t=90s için H_p-L, MOC-STAR Grafiği, (b) t=90s için $V_{akış}$-L, MOC-STAR Grafiği

Sonuç ve Öneriler

Çalışmada Star CCM⁺ programı ile 600mmx900mm yumurta kesitli, 1/1000 eğimli ve 20 m uzunluğundaki boru hattı çalışılmıştır. Çalışma yapılırken kararsız akım koşulları dikkate alınarak, t=156s işletme yapılmış ve 6s'de bir çalışma sonuçlarının 5m'de bir alınan kesitlerdeki piyezometre yükseklikleri ile akış hızları alınmıştır. Karakteristikler yöntemi ile hesaplama yapılabilmesi için başlangıç ve bitiş kesitleri olan Kesit 0 ve Kesit 20 ye ait 6s'de bir veriler Star CCM⁺ programından alınmıştır.

MOC hesabında serbest yüzeyli akış özelliği ile tedrici değişen akım özelliğine göre hesaplama yapıldığı için açık kanal şeklinde çözülmüştür. t=0 anındaki kararlı duruma ait Kesit 0-5-10-15-20'ye ait hız ve piyezometre yükseklikleri işletilen Star CCM⁺ programından alınmıştır. Daha sonra Kesit 0 ve Kesit 20 için 6s'de bir alınan veriler ile Kesit 5-10-15 e ait H_p ve $V_{akış}$ değerleri serbest yüzeyli MOC hesap esaslarına göre analitik olarak hesaplanmıştır. Burada zamana bağlı değişkenlikler olduğu için her kesitte sediment birikimi söz konusu olacağından boru taban kotu sediment üst kotu olarak kabul edilerek MOC hesabında, her kesitte manning kompozit değerleri değişeceğinden hesaplamalara bu durum katılmıştır. Star CCM⁺ programı işletme çalışmalarından alınan H_p ve $V_{akış}$ değerlerinden

yararlanılarak Q debi (m^3 s^{-1}) hesaplanmıştır. Hesaplanan Q verilerinin birbirleri ile uyumluluğunu ortaya koymak için istatistiksel analiz uygunluk testi olarak ki-kare kullanılarak yapılmıştır.

Ki-kare testi, gözlenen frekanslar (f_o) ile beklenen frekanslar (f_i) arasındaki farkın istatistik olarak anlamlı olup olmadığı temeline dayanır (14). Ki-kare testinde, niteliksel olarak belirtilen veriler kullanılır.

Ki-kare dağılımı, genellikle iki bağımsız niteliksel kriteri test etmek için kullanılır. Sıfır hipotezi (H_0), iki kriterin bağımsız olduğunu; araştırma hipotezi(H_A) ise, iki kriterin arasında ilişki olduğunu ifade eder (Güngör ve Bulut, 2008).

$$\chi^2_{hes} = \sum_{i=1}^{n} \frac{(f_0 - f_i)^2}{f_i} \tag{14}$$

Khi-Kare dağılımı için 135 adet veri alınmış olup, frekans grup sayısı 8, serbestlik derecesi 7 alınarak %5 hata olasılığıyla çalışılmıştır. Ki-kare testine ait sonuçlar Tablo 3'te verilmiştir.

Tablo 3. Khi-Kare Testi İstatistik Sonuçları

Sıra No	Debi Sınıf aralığı x10^{-3}	MOC Dağılımı f_o	Star CCM$^+$ Dağılımı f_o
1	3.510-53.50	22	20
2	53.51-103.50	31	35
3	103.51-153.50	27	29
4	153.51-203.50	22	22
5	203.51-253.50	25	23
6	253.51-303.50	6	4
7	303.51-353.50	1	1
8	353.51-404.86	1	1
χ^2	0.446<14.07		

Khi-Kare dağılımı incelendiğinde test istatistikleri serbestlik derecesine göre hesaplanan kritik değer χ^2=14.07 den küçük olduğu için hipotez uygun bulunmuştur. Bu durum karakteristikler yöntemi ile Star CCM$^+$ programı çıktılarının birbiriyle uyumlu sonuçlar gösterdiğini ortaya koymuştur.

Bu çalışmada hesaplamalı akışkanlar dinamiği programı olan Star CCM$^+$ ile kararsız akış koşulları altında hesaplanan serbest yüzeyli yumurta kesitli boru hattının farklı zaman aralıklarındaki, eşit aralıklı kesitlerindeki piyezometre yükseklikleri ile akış hızları alınmıştır. Serbest yüzeyli akış prensiplerine göre analitik metot olan Karakteristik yöntemi ile Star CCM$^+$ programında alınan H_p ve $V_{akış}$ değerleri ortaya konmuştur. Her iki çıktıyı istatistiksel olarak değerlendirebilmek amacıyla Q debi hesaplamaları yapılmıştır. Daha sonra khi-kare testine tabi tutularak çıktıların birbirleri ile uyumlulukları ortaya konmuştur. Kübik spline grafikleri de çizilerek her 6s'de bir H_p ve $V_{akış}$ değerlerinin grafikleri çizilerek bu grafiklerin denklemleri hesaplanmıştır. Çalışmada bu grafik ve denklem sayıları çok fazla olacağı için örnek olması açısından Şekil 8.'de t=90s'ye ait grafik ve denklemler verilmiştir. Bu grafiklere göre de çıktıların birbiri ile uygun olduğu da görülmektedir.

Çalışma hem nümerik hem de analitik bir çözüm yönteminin karşılaştırılma esasına dayanmakta ve çıkan sonuçların uyumlu olmasından dolayı bu tarz çalışmalara fayda sağlayacaktır. Böylece nümerik analiz programlarının da güvenilirliğine katkı sağlamıştır. Çalışmada kullanılan yumurta kesit farklı boyutlarda, farklı eğimlerde kullanılarak, pürüzlülük değerlerinin de değiştirilmesi ile birlikte çeşitli hesaplamalar da yapılabilir Ayrıca farklı t zamanlarda ve zaman aralıklarında çalışılarak değerler ortaya konabilir.

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Etik

Bu makalenin yayınlanmasıyla ilgili herhangi bir etik sorun bulunmamaktadır.

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Yazar herhangi bir çıkar çatışması olmadığını belirtmektedir.

ORCID

Esin Acarı https://orcid.org/0000-0002-3926-2804

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Sıkıştırma ile Ateşlemeli Bir Motor Silindirinin Sıkıştırma Zamanında Kompresyon Segman Yuvası Boşluğunda Oluşan Akışın İncelenmesi

Hüdagül Değirmenci[1], Emrah Kantaroğlu[1]

[1]Kırıkkale Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, Makine Mühendisliği Bölümü, Kırıkkale

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Öz

Sıkıştırma ile ateşlemeli motorların çalışma prensibi olarak ortaya çıkan, silindir içerisindeki yüksek sıkıştırma ve buna bağlı gerçekleşen yanma olayı sonucunda, yanma odasındaki gazlar genleşir ve güç üretilir. Silindirin sahip olduğu yüksek sıcaklık ve basınç nedeniyle yapısal ve termal yükler ortaya çıkar. Bununla beraber akış hattı içerisinde de farklı enerji kayıpları veya dönüşümleri eş zamanlı olarak gerçekleşir. Bu çalışmada sıkıştırma ile ateşlemeli Renault F8Q706 motorunun bir pistonunun kompresyon segmanı yuva boşluğundaki kaçak debi, hız ve sıcaklık dağılımları sayısal olarak incelenmiştir. İncelemeler 2500d.dk^{-1} motor devrinde, tam yükte ve sıkıştırma sonu piston üst ölü noktadayken hesaplamalı akışkanlar dinamiği (HAD) yöntemiyle yapılmıştır. İncelemelerde sıkıştırma sonunda, yanma başlamadan önceki sıkıştırılmış hava dikkate alınmış ve analizler buna göre yapılmıştır. 2-Boyutlu (2B) segman yuvası boşluğu HAD analizlerindeki sınır şartları, Ricardo-Wave yazılımı ile oluşturulan 1-Boyutlu (1B) motor modelinden ve literatürden alınmıştır. Segman yuvası boşluğunun 2B çizimi SolidWorks yazılımında ve HAD analizleri ANSYS-Fluent modülünde yapılmıştır. Bu kapsamda, girişte 3MPa, 5MPa ve 7,5MPa giriş basınçlarına karşılık, segman yuvasındaki boşluk havasındaki kaçak debi sırasıyla 0,01569436, 0,01569455, 0,01569465 kg s^{-1} olarak gerçekleşmiştir. 7,5 MPa giriş basıncında toplam gaz sıcaklığı en yüksek 4069,244 K, akışkan hızı ise 0,6885588 m s^{-1} olarak hesaplanmıştır. Yüksek sıkıştırma oranına bağlı olarak, giriş basıncının artması ile segman yuvası boşluğundaki kaçak debi, sıcaklık ve hız değerleri artmıştır.

Anahtar Kelimeler: motor performansı, kompresyon segmanı, segman yuvası, sızdırmazlık, HAD

Investigation of the Flow in the Compression Ring Groove of a Compression-Ignition Engine Cylinder During the Compression Stroke

Abstract

In compression-ignition engines, the principle of operation involves high compression in the cylinder, leading to combustion that expands gases in the combustion chamber and generates power. The high temperature and pressure within the cylinder result in structural and thermal loads, along with simultaneous energy losses or transformations in the flow path. This study numerically investigates the leakage flow rate, velocity, and temperature distributions in the compression ring groove of a Renault F8Q706 engine piston. Using Computational Fluid Dynamics (CFD) analysis, the study was conducted at 2500 rpm, full load, and at the top dead center of compression. The compressed air before combustion was considered in the analysis. The 2D geometry of the ring groove was modeled using SolidWorks, and CFD simulations were performed with ANSYS Fluent, using boundary conditions from a 1D motor model created in Ricardo-Wave software and literature. Results indicate that for inlet pressures of 3 MPa, 5 MPa, and 7.5 MPa, the leakage flow rates were 0.01569436, 0.01569455, and 0.01569465 kg.s^{-1}, respectively. At 7.5 MPa, the maximum gas temperature reached 4069.244 K, and the fluid velocity was 0.6885588 m.s^{-1}. It was observed that as the inlet pressure increased, the leakage flow rate, temperature, and velocity within the ring groove space also increased due to the high compression ratio.

Keywords: engine performance, compression ring, ring groove, sealing, CFD

Sorumlu Yazar / Corresponding Author: Emrah Kantaroğlu emrahkantaroglu@kku.edu.tr

Giriş

Çevresel etkilerle beraber her geçen gün sıkılaştırılan emisyon standartları, enerjinin verimli ve daha çevreci kullanımını teşvik etmektedir. İçten yanmalı motorlar yüksek güç ve menzil avantajlarından dolayı tercih edilse de artan çevresel sorunlarla birlikte kullanımı günümüzde azalmaktadır. Bu çevresel sorunların başını, kirletici ve sera gazı etkisi yapan emisyonlar çekmektedir. Bu nedenle, araştırmacılar için yenilenemeyen petrol türevli fosil yakıt kullanımının daha az kullanılarak yüksek verimle güç üretilmesi başlıca araştırma konuları olmuştur. Bunun için ise en klasik yöntemler olarak motor geometrisi değişiklikleri yapılmış ve yeni yakıt arayışları denenmiştir. Ancak günümüzde gelişen dijital teknolojiler ve elektrik altyapılarıyla birlikte, trend elektrikli otomobillere doğru kaymaya başlamıştır. Bu da ulaşımda içten yanmalı motor kullanımını iyiden iyiye kısıtlamaya başlamış ve alternatif bir ulaşım imkânı sağlayacak olan elektrikli otomobil teknolojileri hızla bu çalışmaların esas konusu haline gelmiştir. Dünyada, 2035'ten itibaren benzin ve dizel yakıt kullanımı birçok ülke tarafından kısıtlanacak veya kullanımdan kaldırılacaktır. Türkiye ise Paris Anlaşmasına taraf olup 2030-2050 yılları arasında bu geçişi tamamlamayı taahhüt etmiştir (Türkiye Cumhuriyeti Dışişleri Bakanlığı, 2023). Eylül 2024'te yayınlanan TÜİK verilerine göre Türkiye'deki 14 967 044,00 otomobilin %1,3'ü hibrit ve %0,3'ü tamamen elektriklidir. Yani hali hazırda kullanılmakta olan 14 727 572,00 adet içten yanmalı motora sahip otomobil bulunmaktadır (Türkiye İstatistik Kurumu, 2024). Bu sayılara bakıldığında içten yanmalı motor kullanımı halen devam etmekte ve gündemdeki yerini korumaktadır. Ayrıca güç üretimi sağlanan jeneratörlerde, ağır yük araçlarında, deniz ve demiryolu ulaşımlarında yüksek güç talebinin karşılanması için sıkıştırma ile ateşlemeli motor kullanımı kaçınılmazdır (Kantaroğlu, 2024; Cunanan v., 2021). Sıkıştırma ile ateşlemeli motorlarda kullanılan dizel yakıtın yüksek sıkıştırma ile kendiliğinden patlaması sayesinde güç üretimi sağlanır. Bu işlem sırasında motordaki ısı, efektif işe dönüşürken çeşitli kayıplar da yaşanmaktadır.

Bu noktada, sıkıştırma sonu basıncın kayıp vermeden en yüksek değere ulaşması da bu motorlarda verim artışına neden olmaktadır. Bu kaybın önüne geçmek için kompresyon segmanları kullanılır. Bu segman, sıkıştırma sırasında pistonun üst bölümünde yer alan yüksek basınçlı havanın, alt bölüme (krank mili-karter) geçmemesini ve dolayısıyla basınç kaybı yaşanmamasını sağlar. Kompresyon segmanı bu görevi ile bir sızdırmazlık elemanı olarak görev yapmaktadır. Yeşilada (1997), Piston segmanlarının, içten yanmalı motorlardaki kritik işlevini ve sızdırmazlık elemanı olarak rolünü vurgulamış, bu elemanların motor performansına etkilerini analiz etmiştir. Chucholowski vd. (1982) ve Kornprobst vd. (1987), yaptıkları çalışmalarda, tüm piston silindir düzeneğinin ilk 2B HAD simülasyon modelini geliştirdiler. Çalışmalarında, piston dinamiği, piston segmanı dinamiği ve gaz dinamiği dikkate alınarak radyal film kalınlığını ve hidrodinamik sürtünmeyi hesapladılar. Bu sayede segmanlar ve piston olukları arasındaki etkileşimi analitik denklemlerle açıklamışlardır. Furuhama vd. (1960), segman halka boşluklarında gaz taşınması üzerine teorik ve deneysel incelemeler yaptılar. Karamangil (2004), çalışmasında, yanma odası gazları için termodinamik modeller ve segmanda yer alan hidrokarbonlar için nümerik modellemeler yapmıştır. Modelleme sonucunda segman yuvası boşluğunda yer alan hidrokarbonların yanma olayından daha uzun bir sürede silindirden ayrıldığını tespit etmiştir. Lyubarskyy ve Bartel (2016), yaptıkları çalışmada, dizel yakıtlı bir motorun piston segmanları üzerinde 2 boyutlu CFD modeli oluşturmuşlardır. Analizlerinde segman üzerindeki halka boşlukları boyunca kütle akışını dikkate alarak, basınç ve akışkan sürtünmelerini incelemişlerdir. İncelemeler sonunda artan ortalama basınca göre segman halkası boşluklarında artan akış kayıpları tespit etmişlerdir. Namazian ve Heywood (1982), buji ateşlemeli motorlarda piston, silindir ve segman yuvalarındaki akışların motor performansı üzerindeki etkisini incelemişlerdir. Bu bağlamda hidrokarbon emisyonları, enerji kayıpları ve verimlilikte meydana gelen değişimleri CFD analizleri ile kapsamlı bir biçimde yapmışlardır. Koszalka ve Suchecki (2017), çalışmalarında piston segmanlarında meydana gelen gaz akışını ve ters gaz akışını matematiksel olarak modellemişlerdir. Koszalka (2019), bir diğer çalışmasında bir dizel motorun piston, silindir ve segman akışını kaçak debi ve basınçlar özelinde aynı matematiksel model ile incelemiştir.

Literatürde yanma odasında yüksek basınç elde edilmesini sağlayan kompresyon segmanlarının, basınç kaybı ve kaçak debileri yeterince incelenmemiştir. Enerji verimliliği açısından önem arz eden bu konu alternatif yakıt çalışmalarının yanında dikkate değer konu olmakla beraber, her bir motora özgü olarak incelenme potansiyeline sahiptir. Bu çalışmada, Renault F-Type F8Q motorunun demontajı gerçekleştirilerek, birebir silindir ölçüleri alınmış, piston segman arasındaki akış hacminin geometrisi oluşturulmuştur. Oluşturulan ölçüler ve motorun fiziksel özellikleri kullanılarak motor ilk olarak, Bayram ve Kantaroğlu 'nun çalışmasındaki gibi 1B olarak modellenmiştir (Bayram ve Kantaroğlu, 2024). Literatürdeki motor testleri ile doğrulanmış olan motor modelinden alınan silindir içi karakteristikler ANSYS-Fluent Modülünde sınır şartı olarak kullanılarak farklı giriş koşullarına göre segman yuvası boşluğundaki akış analizleri gerçekleştirilmiştir. Çalışma sonunda segman yuvası boşluğundan kaynaklanan basınç kaybı ve kaçak debiler incelenmiştir.

Materyal ve Yöntem

Bu çalışmada, segman yuvası boşluğundaki HAD analizlerinin yapılabilmesi için Renault F8Q706 motoru öncelikle Ricardo-Wave yazılımında 1B olarak modellenmiştir (Bayram ve Kantaroğlu, 2024). 1B motor modeli analizlerinin, literatürde yer alan test sonuçlarıyla doğrulanmasının ardından, elde edilen silindir içi karakteristikler 2B segman yuvası boşluğu analizlerinde sınır şartı olarak kullanılmıştır.

1B Motor Modeli

Bu çalışmada Ricardo-WAVE 2019.1 yazılımı kullanılarak 1B model oluşturulmuştur. 1B motor modeli analizleri çözüm mantığı gereği, ana akış yolu üzerindeki her bir bileşenin ilgili özelliklerinin tanımlanarak motor bileşenleri arasında bir ağ kurma şeklinde oluşturulmuştur. Bu yöntemde, sisteme eklenen her bir bileşen akışkan akışı, ısı transferi, termodinamik, yanma ve emisyonun birçok fiziğinin tanımlaması yapılır. Bu yazılımda korunum denklemlerinden sıkıştırılabilir gaz akışları için kütle, momentum ve enerji transferi 1B formunda çözülür. Bunun yanında modellemede yanma ve emisyonlar için alt modeller bulunmaktadır. 1B motor modeli oluşturulurken akış sürtünmesi, türbülans, ısı transferi, yanma, emisyon için bu modeller kullanılır. Birçok motor bileşeni, 1B motor modeli yazılımı kütüphanesinde modüler olarak mevcuttur. 1B motor modelindeki her bir bileşen, test donanımı ve test edilen motor için geçerli olan ilgili geometrik ve fiziksel parametreler kullanılarak tanımlanmıştır. Motorla ilgili parametreler motorun teknik özelliklerinin yer aldığı motor kataloğundan ve literatürden elde edilmiştir (Caro vd., 2001). Bu özellikler Tablo 1 ve Tablo 2'de verilmiştir. Wave programında 1B simülasyonlar için aşağıdaki modeller kullanmıştır.

Isı transferi modeli olarak Woschni modeli kullanılmıştır (Woschni, 1967). Yanma modellemesi için Wiebe yanma modeli kullanılmıştır (Ghojel, 2010; Wiebe, 1956). Emisyonlar için, CO ve CO_2 için Newhall emisyon modeli (Newhall, 1969), HC oluşumu için Cheng HC emisyon modeli (Cheng vd., 1993), NO_x için Zeldovich oluşum mekanizmalarına dayanan Fenimore modeli (Fenimore, 1971) ve Heywood korelasyonları kullanılmıştır (Heywood, 1988). Mekanik kayıpların hesaplanmasında literatürde %10 hata payına sahip olduğu bilinen Chen-Flynn korelasyon modeli kullanılmıştır (Pipitone, 2009).

Yakıt tanımlaması Wave içerisindeki hazır dizel yakıt olarak kullanılmıştır. Krank açısına göre sıcaklık, basınç, akış ve emisyon gibi temel fiziksel büyüklükleri okumak için modelin belirli noktalarına sensörler ve debimetreler yerleştirilmiştir. Motor devri olarak maksimum tork devri olan 2500 $d.dk^{-1}$ alınmıştır. Her bir motor test koşulu için, veriler okunmadan önce tamamen kararlı durum koşullarının sağlanması amacıyla 250 motor çevrimi üzerinde analizler gerçekleştirilmiştir. Zaman adımı çarpanı ve yakınsama kriteri sırasıyla 0,1 ve 0,001 olarak ayarlanmıştır. Şekil 1'de gösterildiği gibi, 1B motor modelindeki bileşenler; filtre, emme hattı, emme havası debimetresi, gaz kelebeği valfi, emme manifoldu portu, emme valfi, yakıt hattı, silindir, piston, motor bloğu, egzoz valfi, egzoz manifoldu portu ve egzoz hattı şeklindedir. 1B motor modelinde her bir bileşen ilgili özellikleri tanımlanarak ayrı ayrı oluşturulmuş ve uygun ilişkiler ve sınır koşullarıyla birbirine bağlanmıştır. 1B modelinde sınır koşulları olarak tanımlanması gereken bazı önemli sıcaklık değerleri vardır (Tablo 2). Bu sıcaklıklar motor hızına bağlı

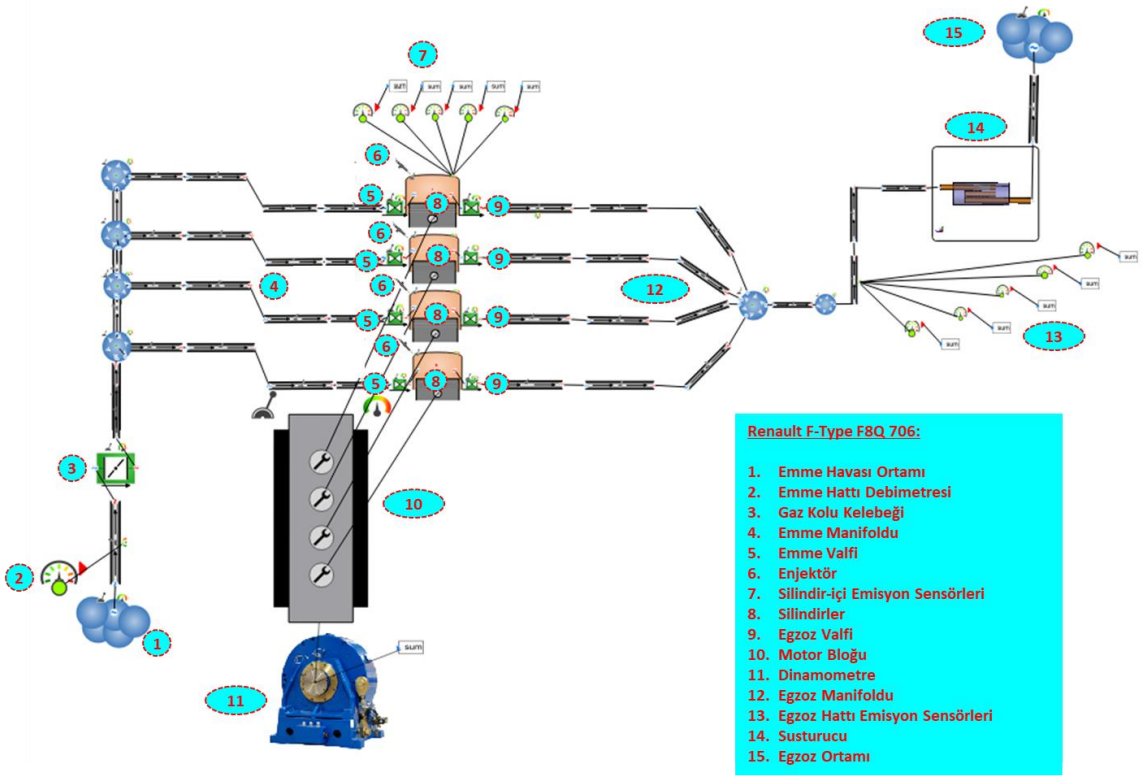
olarak piston sıcaklığı, silindir kafası/duvar sıcaklığı, emme/egzoz valfi sıcaklığıdır. Kodda kullanılan bu sabitler yaygın literatürdeki veriler kullanılarak belirlenmiştir (Aktaş, 2021; Bayram ve Kantaroğlu, 2024; Heywood, 1988; Mahle, 2012; Winterbone, 2015). 1B motor modeli, motor testlerinde kullanılan koşullar altında çalıştırılmıştır. Sıcaklık, basınç, emisyon gibi gerekli fiziksel büyüklüklerin okunması için model üzerinde belirli noktalara birçok sensör yerleştirilmiştir.

Tablo 1. Motor Özellikleri (Caro vd., 2001; Bayram ve Kantaroğlu, 2024).

Motor Modeli	Renault F-Type F8Q 706
Silindir sayısı	4
Strok hacmi, cc	1 870
Motor ağırlığı, kg	163
Piston çapı, m	0,08
Strok mesafesi, m	0,093
Sıkıştırma oranı	21,5: 1
Maksimum tork, Nm 2500 d dk^{-1}	118
Maksimum güç, kW 4500 d dk^{-1}	47

Tablo 2. Sınır Şartları (1B Model) (Aktaş, 2021; Bayram ve Kantaroğlu, 2024; Heywood, 1988; Mahle, 2012; Winterbone, 2015).

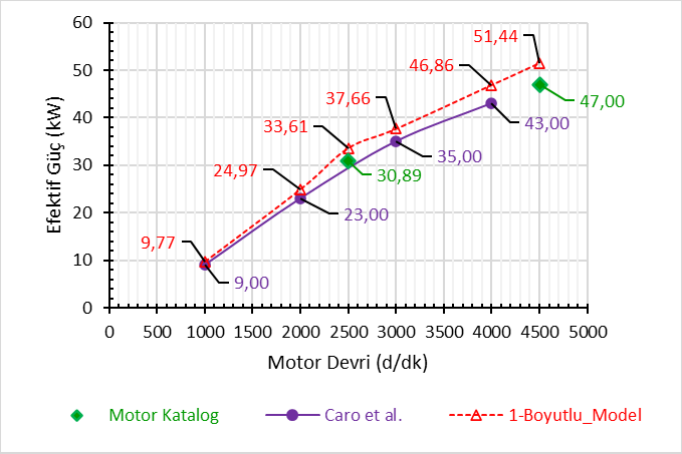
Sınır Şartları	Basınç (Bar)	Sıcaklık (K)
Emme Havası Ortamı	2,56	327,5
Egzoz Ortamı	2,83	904
Piston	-	595
Emme Manifoltu	-	323
Egzoz Manifoltu	-	490
Silindir Gömleği	-	616
Piston Kafası	-	635
Emme Valfi	-	345
Egzoz Valfi	-	500



Şekil 1. 1B Modeli

1B model doğrulamalarında motor katalog güç değerleri ve literatürde aynı motor için yapılan deneysel çalışmalardan yararlanılmıştır. 1B modelin doğrulanmasına yönelik karşılaştırmalar Şekil 2'de verilmiştir (bayram ve Kantaroğlu, 2024). 1B modelde dizel yakıt için tam yükte elde edilen güç parametresi incelendiğinde, katalog ve literatür çalışmasında yer alan güç parametrelerinin de aynı artışı gösterdiği görülmektedir (Caro vd., 2001; Engine catalog, 2021). 1B motor modelindeki güç parametresi, literatür test çalışmasında yayınlanan güç parametresinden 1 000-2 000-3 000-4 000 d dk^{-1} için sırasıyla %8,526-%8,555-%7,596-%8,965 daha fazladır. Benzer şekilde 1B motor modelinde hesaplanan güç parametresi motor katalog güç parametresine göre 2 500 d dk^{-1}'da %8,785 ve 4500 d dk^{-1}'da %9,457 daha yüksektir.

Motor katalog gücü ile literatürdeki diğer çalışmalardan elde edilen motor güçleri ile mevcut 1B motor modeli koşulları (dizel içeriği, ortam koşulları, motor aşınması vb.) arasında farklılıklar bulunmaktadır. Yani 1B modelde gözlenen farklılıklar model yaklaşımlarından kaynaklanmaktadır. 1B model analizlerindeki bu farklılığın temel nedeni, emme havası ve egzoz gazı basınç ve sıcaklıklarındaki farklılıktır. Buradan da anlaşılacağı üzere bu çalışmada modellere test koşulları mümkün olduğu kadar doğru şekilde uygulanmıştır. 1B modellemede motorun maksimum tork devri olan 2 500d/dk ve tam yük koşulları için sıkıştırma sonunda enjeksiyon öncesinde silindir içi gaz sıcaklığı ve basıncı hesaplanmıştır. Bu değerler Tablo 3'te verilmiştir.



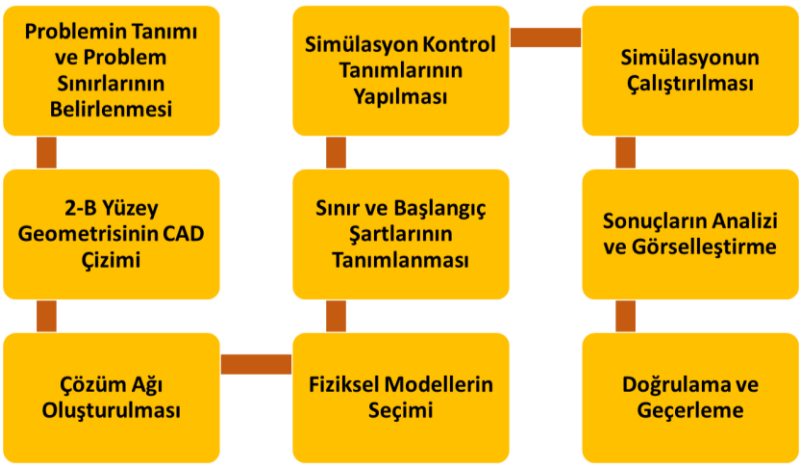
Şekil 2. 1B Modeli ve Test Doğrulamaları (Bayram ve Kantaroğlu, 2024).

Tablo 3. 2B Segman Boşluk Modelinde Kullanılan ve 1B Motor Modelinden Alınan Silindir İçi Parametreler

Sıkıştırma Sonu Silindir İçi Hava Özellikleri	
Basınç, MPa	7,5
Sıcaklık, K	2 000

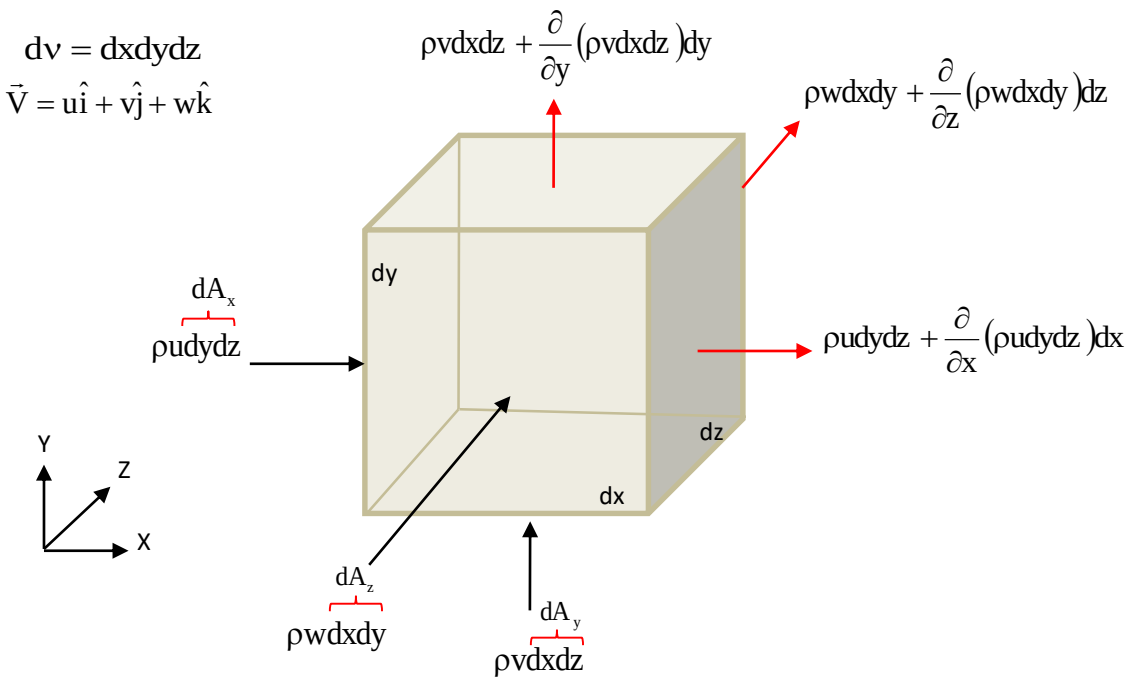
2B Segman Yuvası Boşluğu HAD Modeli

HAD analizleri, tasarım aşamasındaki ya da hali hazırda kullanılmakta olan ısıl-akış problemlerinin hesaplanmasında kullanılır. Bu analizlerde, problem durumuna göre giriş ve çıkış yapılan sistemin tamamını kapsayan bir ağ yapısı kullanılarak, akış hattındaki akışkan hareketi için kütle, momentum, enerji korunum denklemlerini çözülmektedir. Bu çözümler zamandan bağımsız olabildiği gibi, zamana bağlı olarak da yapılabilmektedir. Aynı zamanda statik akış geometrileri olduğu gibi hareketli yapılar da olmaktadır. Bu durumlarda da adaptif ağ yapıları ile sistemler çözümlenmektedir. Ağ yapıları üzerinde çözülmek istenen korunum denklemleri homojen olmayan kısmi türevli diferansiyel denklem takımlarından oluşturmaktadır. Bu denklemlerin analitik çözümü mümkün olmadığından sayısal çözüm yöntemi olarak sonlu farklar yöntemiyle çözüm yapılmaktadır. Bu çalışmada ANSYS-Fluent 2022 R1 modüllü kullanılmış ve segman boşluk analizleri gerçekleştirilmiştir. HAD analizlerinde üç önemli temel adım bulunmaktadır. Bu adımlardan birincisi pre processing adımı, ikincisi solver adımı ve üçüncüsü post processing adımlarıdır. Bu çalışmadaki HAD modeli oluşturma aşamaları Şekil 3' te gösterilmiştir.



Şekil 3. HAD Modeli İşlem Basamakları

Bir akış sırasında, herhangi bir akışkan diferansiyel elemanına ağırlık, atalet, basınç ve sürtünme kuvvetleri etki eder. Bu kuvvetler de diferansiyel elemanda sürekli olarak hız değişimine neden olur. Benzer şekilde, iletim, taşınım, ışınım kaynaklı ısı akıları da diferansiyel elemanda sıcaklık değişimlerine neden olur. Bu değişiklikler her ne kadar akışkan diferansiyel elemanı üzerinde etkili olsa da fiziksel olarak eleman üzerinde kütle, enerji ve momentum korunumu vardır. Her eksen doğrultusunda, binlerce veya milyonlarca diferansiyel elemana reynolds transport teoremi (kütle, enerji, momentum korunumu) uygulanarak, analitik çözümü olmayan karmaşık denklemlere, sayısal çözümlemede sonlu farklar metoduyla (The Finite Difference Method) çözüm getirilir. Model içerisindeki diferansiyel elemanlardaki korunumlar bu denklemler ile çözülür ve oluşturulan matris sayesinde sonuca ulaşılır. Şekil 4' te yer alan bir diferansiyel elemana giriş ve çıkış yapan kütleler cinsinden vektörel formadaki kütlenin korunumu (süreklilik), Eşitlik 1' deki gibi yazılmıştır.



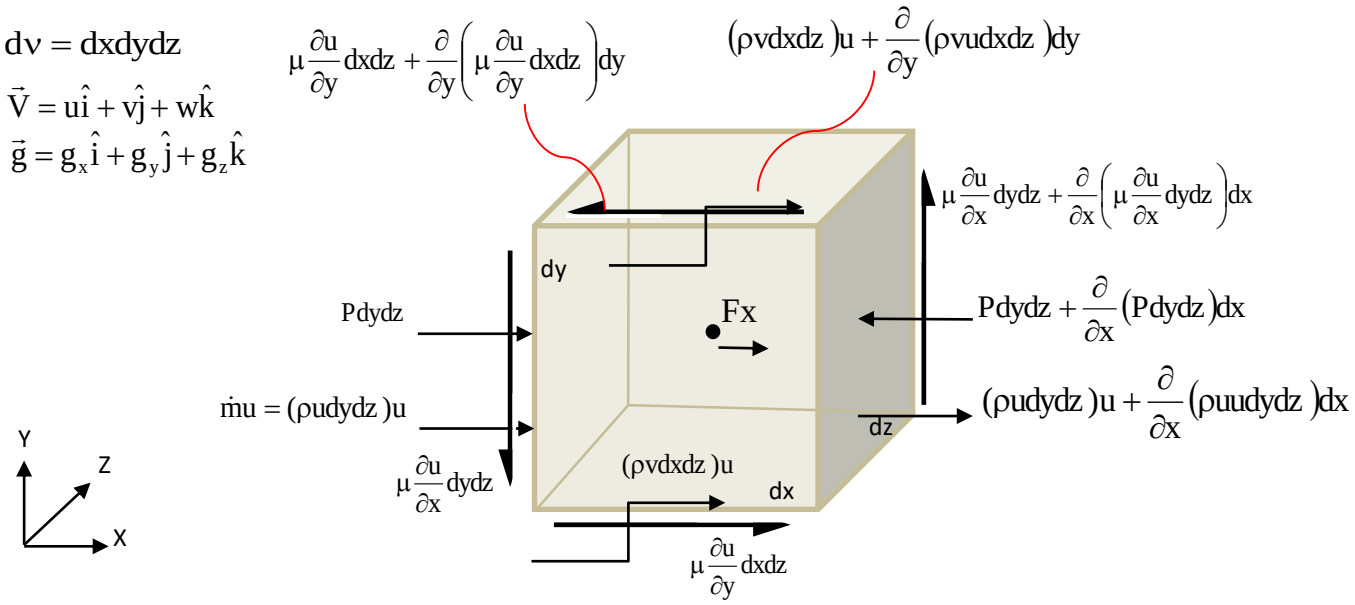
Şekil 4. Diferansiyel Elemanda Kütle Giriş Çıkışı

$$\rho\vec{\nabla}.\vec{V} = \rho\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right) \quad (1)$$

Süreklilik denklemi, vektörel formda, yoğunluğun yerel değişimi (maddesel türev) ve gradyan vektörü ile Eşitlik 2' de yazılmıştır.

$$\frac{D\rho}{Dt} + \rho\vec{\nabla}.\vec{V} = 0 \quad (2)$$

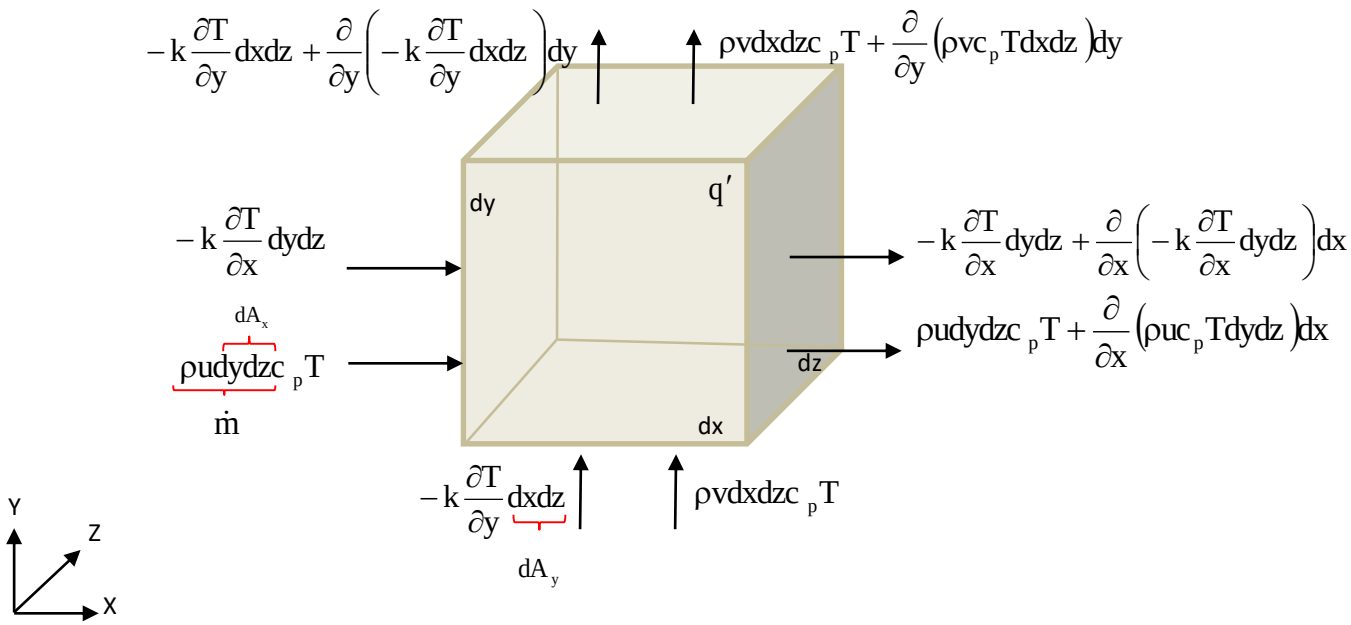
Şekil 5' de kartezyen koordinatlarda, bir akışkan diferansiyel elemanına Newton'un ikinci hareket kanunu uygulandığında; vektörel formda, sabit viskoziteli ve sıkıştırılamaz akış için Eşitlik 3 elde edilir.



Şekil 5. Diferansiyel Elemanında Momentum Değişimi

$$\rho\frac{D\vec{V}}{Dt} = \vec{f} - \vec{\nabla}P + \mu\nabla^2\vec{V} \quad (3)$$

Şekil 6' da kartezyen koordinatlarda, bir akışkan diferansiyel elemanına termodinamiğin birinci kanunu uygulandığında; vektörel formda Eşitlik 4 elde edilir.



Şekil 6. Diferansiyel Elemanında Enerji Değişimi

$$\frac{DT}{Dt} = \alpha\nabla^2 T + \frac{q'}{\rho c_p} \tag{4}$$

Viskoz ısı üretiminin ihmal edilmediği durum Eşitlik 5' de verilmiştir.

$$\frac{DT}{Dt} = \alpha\nabla^2 T + \frac{q'}{\rho c_p} + \frac{\Phi}{\rho c_p} \tag{5}$$

ANSYS-Fluent HAD analizlerinde kullanılan süreklilik denklemi, Eşitlik 6' da gösterilmiştir.

$$\frac{\partial \bar{\rho}_k}{\partial t} + \nabla.(\bar{\rho}_k \tilde{u}) = \nabla.\left[\bar{\rho} D_T \nabla\left(\frac{\bar{\rho}_k}{\bar{\rho}}\right)\right] + \dot{\bar{\rho}}^c{}_k + \dot{\bar{\rho}}^s{}_k \qquad (k = 1,.....K) \tag{6}$$

Eşitlik 7'de ANSYS-Fluent HAD analizlerinde kullanılan momentum korunum denklemi gösterilmiştir.

$$\frac{\partial \bar{\rho}\tilde{u}}{\partial t} + \nabla.(\bar{\rho}\tilde{u}\tilde{u}) = -\nabla\bar{\rho} + \nabla.\bar{\sigma} - \frac{2}{3}\bar{\rho}\tilde{k}l + \overline{F}^s + \overline{\rho g} \tag{7}$$

Eşitlik 8' de ANSYS-Fluent HAD analizlerinde kullanılan enerjinin korunumu denklemi gösterilmiştir.

$$\frac{\partial \bar{\rho}\tilde{I}}{\partial t} + \nabla.(\bar{\rho}\tilde{u}\tilde{I}) = -\bar{\rho}\nabla\tilde{u} + \nabla\tilde{J} + \bar{\rho}\tilde{\varepsilon} + \dot{\tilde{Q}}^c + \dot{\tilde{Q}}^s \tag{8}$$

ANSYS-Fluent HAD analizlerinde kullanılan k ve ε için RANS denklemi Eşitlik 9 ve 10'da verilmiştir.

$$\frac{\partial \bar{\rho}\tilde{k}}{\partial t} + \nabla.(\bar{\rho}\tilde{u}\tilde{k}) = -\bar{\rho}\tilde{k}\nabla.\tilde{u} + \sigma:\nabla\tilde{u} + \nabla.\left[\frac{(\mu+\mu_T)}{Pr_\varepsilon}\nabla\tilde{k}\right] - \bar{\rho}\tilde{\varepsilon} + \dot{\tilde{W}}^s \tag{9}$$

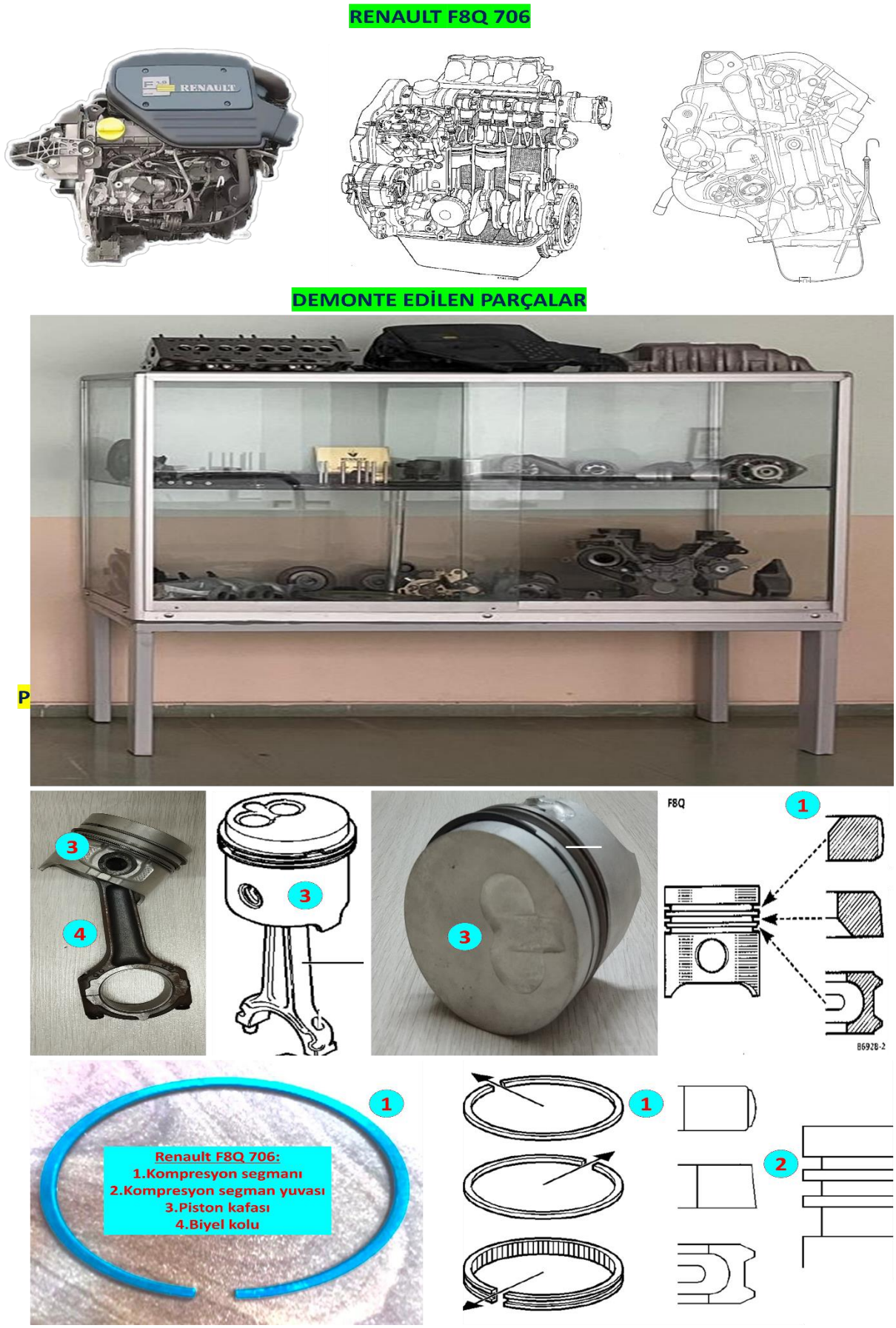
$$\frac{\partial \bar{\rho}\tilde{\varepsilon}}{\partial t} + \nabla.(\bar{\rho}\tilde{u}\tilde{\varepsilon}) = -\left(\frac{2}{3}c_{\varepsilon 1} - c_{\varepsilon 3}\right)\bar{\rho}\tilde{\varepsilon}\nabla.\tilde{u} + \nabla.\left[\frac{(\mu+\mu_T)}{Pr_\varepsilon}\nabla\tilde{\varepsilon}\right] - \frac{\tilde{\varepsilon}}{\tilde{k}}\left(c_{\varepsilon 1}\sigma:\nabla\tilde{u} - c_{\varepsilon 2}\bar{\rho}\tilde{\varepsilon} + c_s\dot{\tilde{W}}^s\right) \tag{10}$$

RNG ε denklemi, Eşitlik 11' de gösterilmiştir.

$$\frac{\partial \bar{\rho}\tilde{\varepsilon}}{\partial t} + \nabla.(\bar{\rho}\tilde{u}\tilde{\varepsilon}) = -\left(\frac{2}{3}c_{\varepsilon 1} - c_{\varepsilon 3}\right)\bar{\rho}\tilde{\varepsilon}\nabla.\tilde{u} + \nabla.\left[\frac{(\mu+\mu_T)}{Pr_\varepsilon}\nabla\tilde{\varepsilon}\right] - \frac{\tilde{\varepsilon}}{\tilde{k}}\left(c_{\varepsilon 1}\sigma:\nabla\tilde{u} - c_{\varepsilon 2}\bar{\rho}\tilde{\varepsilon} + c_s\dot{\tilde{W}}^s\right) - \bar{\rho}R \tag{11}$$

Geometri

Tablo 1' de özellikleri verilen Renault F-Type F8Q706 motorunun, Şekil 7' deki gibi demonte edilmesinden sonra Tablo 4' deki gibi segman ve segman yuvalarının ölçüsü alınmıştır. Tablo 4' de özellikleri verilen ve 2B çizimi yapılan segman geometrisi, bileşen ve yüzey modellemede, sanal montajda ve mühendislik çizimlerinin oluşturulmasında kullanışlı olan 3B modelleme yazılımı SolidWorks paket programı kullanılarak oluşturulmuştur. ANSYS-Fluent' de model dosyası oluşturulurken akışkan hacmi, katı model olarak çizilip akışkan olarak tanımlanmaktadır. Bu nedenle, HAD modeli geometrisi SolidWorks paket programında çizilirken akışkan yüzeyi 2B katı yüzey olarak çizilmiştir. Şekil 8' de 2B HAD analizlerinde kullanılan HAD modeli geometrisi ve model tanımlamalarında kullanılan geometri bölgelerinin isimlendirmeleri verilmiştir.

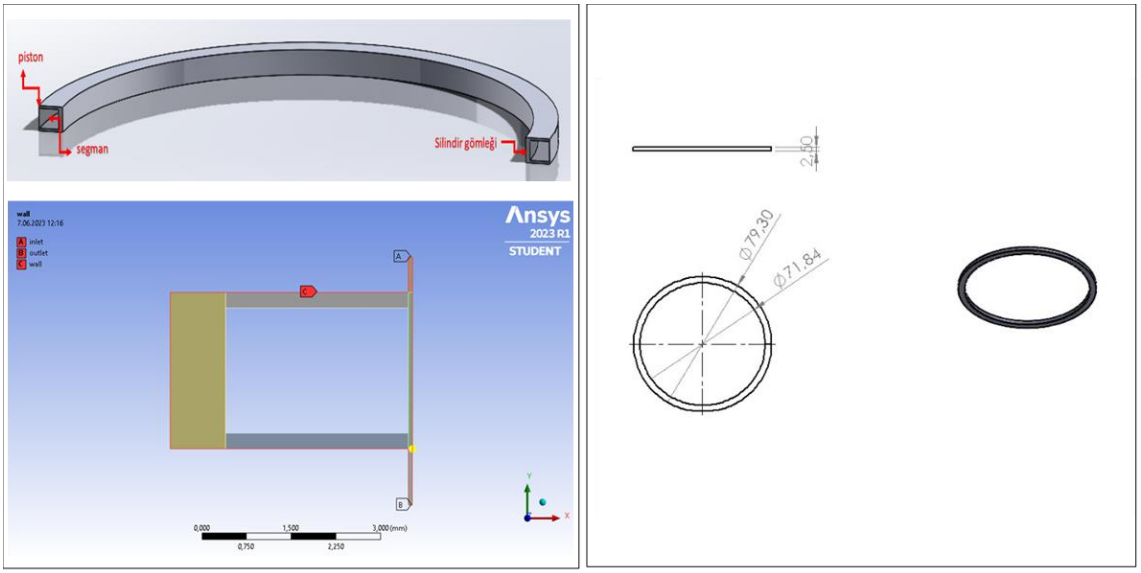


Şekil 7. Motor ve Segman Görüntüleri

Tablo 4. Piston Boyutları ve Özellikleri

Piston Parametresi	Değer*
Kompresyon Yüksekliği	42,25
Yanma Odası Derinliği	0,7
Tam Boy	70,5
Piston Ateşleme Seti Ölçüsü	12,5
Pim Boyu	63
Piston Pimi Çapı	24
1. Segman Eksenel Yüksekliği	2
2. Segman Eksenel Yüksekliği	2
3. Segman Eksenel Yüksekliği	3

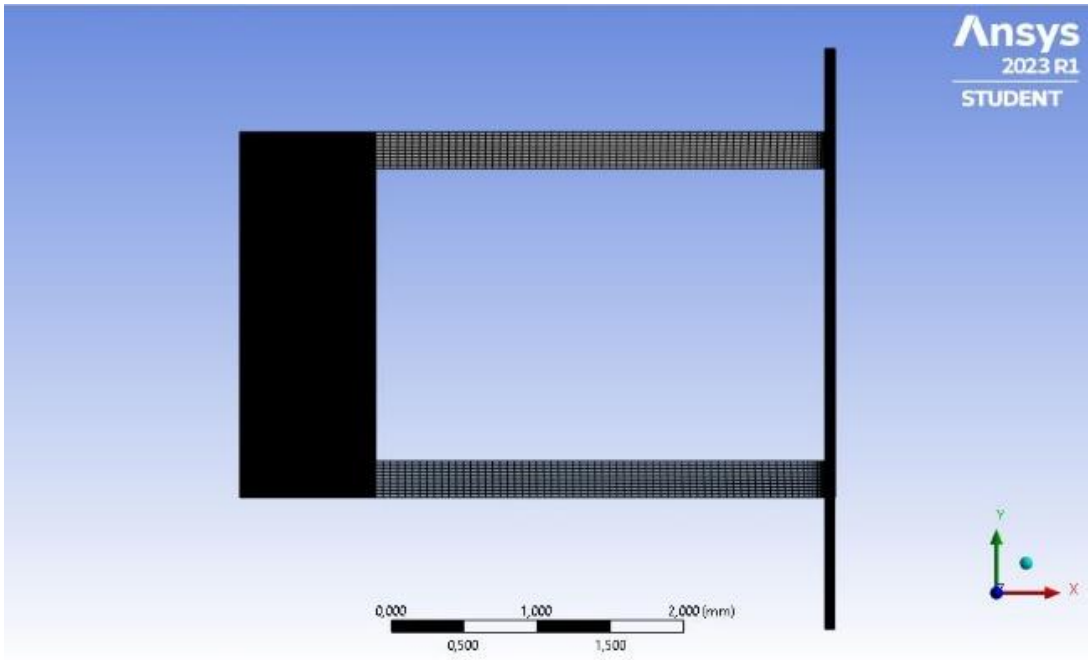
** Uzunluklar mm (milimetre) cinsindendir.*



Şekil 8. HAD Modeli Görüntüsü

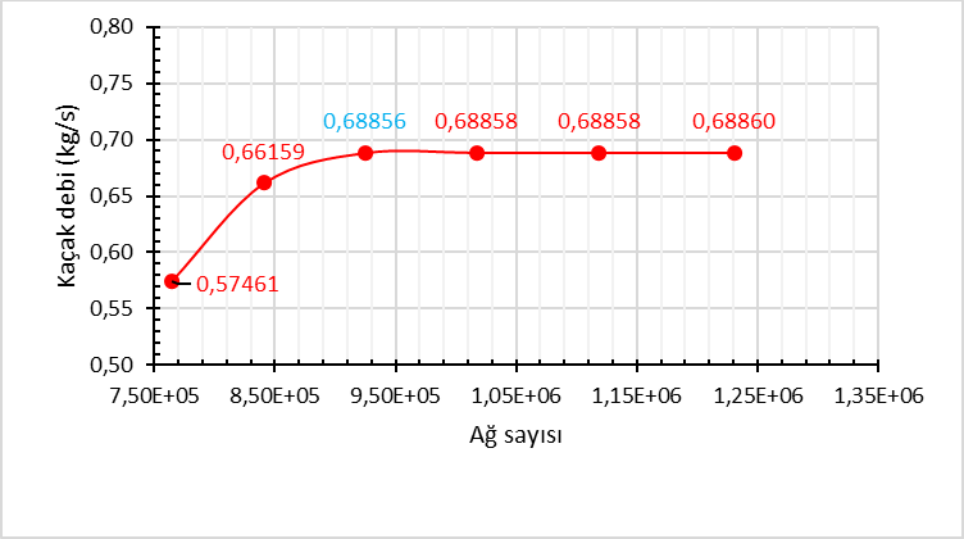
Ağ (Mesh) Yapısı

Karmaşık geometrilerde oluşturulan ağ yapıları sayesinde, akışkan hacmi daha küçük parçalara ayrılarak belirli kısmi diferansiyel denklemler çözülmektedir. Ağ yapıları, problem durumuna göre iki ve üç boyutlu olarak kullanılabilmektedir. Ağ yapısı; body tabanlı, montaj tabanlı ve dinamik olarak üçe ayrılır. Buna bağlı olarak ağ yapıları farklı boyutlarda ve farklı geometrik şekillerde oluşturulabilmektedir. Bu seçim tecrübe gerektiren bir altyapı ile çeşitli deneysel ve analitik yöntemlerle belirlenmektedir. Bu çalışmada oluşturulan kompresyon segmanı yuvası boşluğu mesh yapısı ANSYS-Workbench modülü ile oluşturulmuştur. ANSYS-Workbench'de akış analizleri sırasında mesh metrikleri olan en-boy oranı (aspect ratio) (1 ve 2 arasında) ve narinlik (skewness) (0,9'dan küçük) önemli parametrelerdendir. Bu doğrultuda, mesh yapısı oluşturmak için ANSYS-Workbench'de, geometriye yalnızca element size tanımlaması yapılarak element size değeri 0,001 mm olarak girilmiştir. Ayrıca akışın giriş kenarı, silindir gömlek yüzeyi (piston duvarı) ve motor gövdesi yüzeyi (gömlek duvarı) ve çıkışa ilave ağ hassasiyeti (infilation) tanımlaması da yapılmıştır. Mevcut durumda oluşturulan ağ yapısı eleman sayısı 924 698'dir. Oluşturulan mesh yapısı Şekil 9'da gösterilmiştir.



Şekil9. HAD Modeli Mesh Yapısı

Mevcut analizlerde kullanılan mesh yapısı sayısına bağlı olarak alınan kaçak debi miktarı sonuçlarının, mesh sayısından bağımsız olduğunu göstermek için 7,5 MPa' da mesh sayısından bağımsızlaştırma çalışması yapılmıştır. Bu analizler zamandan bağımsız olarak sıkıştırma sonunda gerçekleştirilmiştir. Mesh bağımsızlık çalışması Şekil 10' da verilmiştir. Burada görüldüğü gibi kaçak debiler mesh sayılarına göre incelendiğinde en stabil ve en efektif mesh sayısının 924 698 olduğu görülmektedir.



Şekil 10. HAD Modeli Mesh Bağımsızlık Çalışması

Model Tanımlamaları

Bu çalışmada piston sıkıştırma zamanı sonunda üst ölü noktadayken sıkışan havanın ne kadarlık miktarının basınç kaybı yaratmak suretiyle pistonun alt gölgesine geçtiği belirlenmiştir. Bu amaçla oluşturulan 2B segman yuvası boşluğu HAD modelinin sınır şartları 1B motor modeli silindir içi karakteristiklerinden alınmıştır. Modelde kullanılan bu sınır koşulları Tablo 5' de verilmiştir.

Tablo 5. Sınır Şartları (2B Segman Yuvası Boşluğu HAD Modeli)

Parametreler	Değerler
Havanın giriş basıncı	7,5 MPa
Havanın çıkış basıncı	100 kPa
Havanın giriş sıcaklığı	2 000 K
Havanın çıkış sıcaklığı	2 000 K

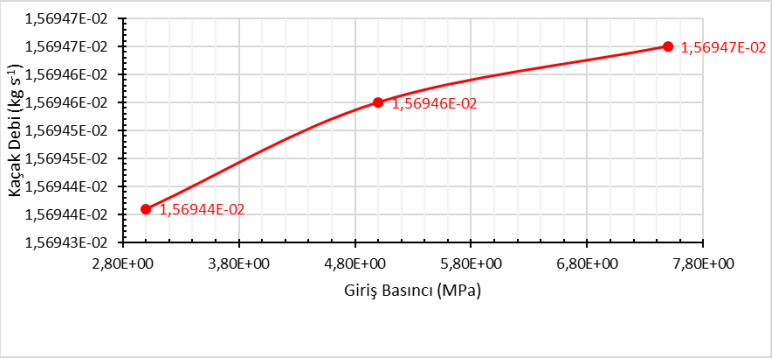
Ayrıca bu çalışmada yakınsama kriteri 1,0 ×10^5 olarak alınmıştır. Türbülans şiddeti %1 olarak alınmış ve çözümlemeler SIMPLE Least Squared Cell Based algoritması kullanılarak yapılmıştır. Türbülans modeli olarak RANS RNG k-ε türbülans modeli standart duvar fonksiyonları kullanılmış ve standart initialization olarak gerçekleştirilmiştir. Ayrıca modelde kullanılan hava, standart hava olarak alınmış olup özellikleri Tablo 6' de verilmiştir.

Tablo 6. Hava Özellikleri

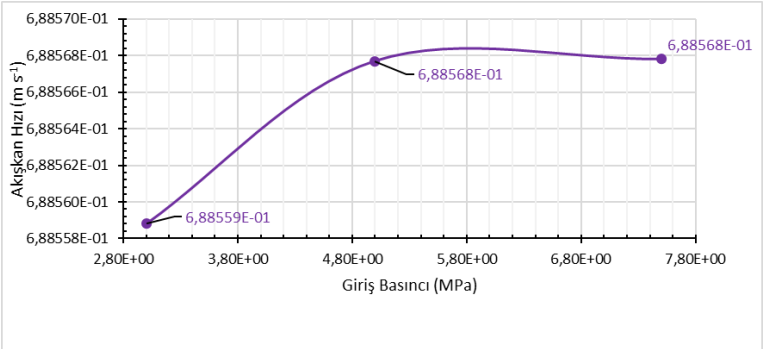
Özellikler	Niceliği
ρ_{hava}, kg m^{-3}	1,225
$C_{p\ hava}$, j kg^{-1} K^{-1}	1 006,43
K_{hava}, W m^{-1} K^{-1}	0,0242
μ_{hava}, Pa. s	1,7894e-05

Bulgular ve Tartışma

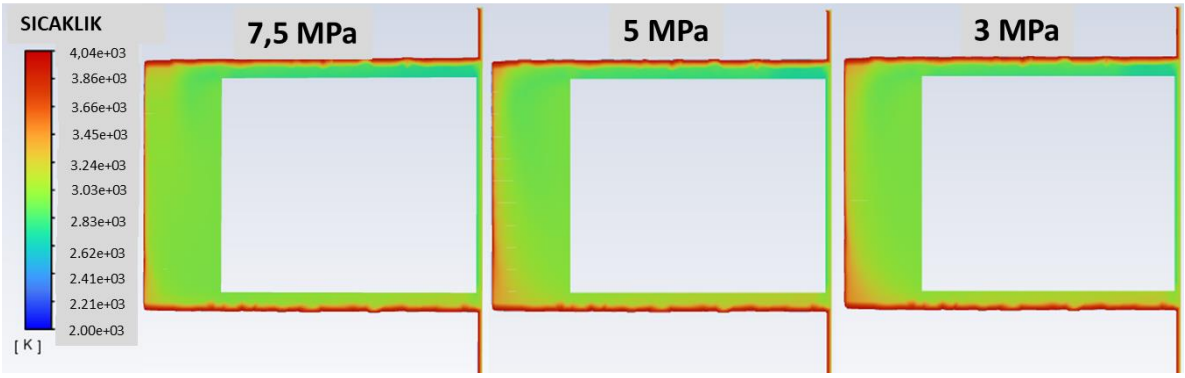
Bu çalışmada, sıkıştırma ateşlemeli F8Q706 motorunun kompresyon segman yuvasındaki boşluğun HAD ile analizleri yapılmıştır. Simülasyonlarda kullanılan sıkıştırma sonu basınçları; 7,5 MPa, 5MPa ve 3MPa şeklindedir. Sıkıştırma ile ateşlemeli motorlarda kullanılan yüksek sıkıştırma oranlarına karşılık herhangi bir basınç kaybı yaratacak durum istenmeyen ve verim azaltıcı bir durumdur. Silindirin içerisinde yaşanan yanma, ısı transferi, sürtünme ve pompalama kayıpları verim kaybına neden olan bu kayıplardır. Motorun emme ve sıkıştırma zamanlarında oluşan pompalama verimi genellikle %95' dir (Heywood, 1988). Pompalama kayıplarının bir kısmı sıkıştırma sırasında emme ve egzoz valflerinden geri kaçan ve kompresyon segmanlarından geriye doğru kaçan basınç kayıplarıdır. Segmanlarda gerçekleşen bu kayıplar iki farklı geometrik özellikten kaynaklanır. Bu geometrik özelliklerden birisi segman bağlantısı için bulunan bilezik boşluğu, bir diğeri de segman yuvasında bulunan boşluktur. Bu çalışmada segman yuvasındaki boşlukta kaynaklanan ve sıkıştırma sırasında basınç kaybına neden olan, boşlukta gerçekleşen kaçak debiler incelenmiştir. Şekil 11' de sıkıştırma sonunda, 1B modelden alınan 7,5MPa değeri ve bu değerden daha aşağıda olan basınçlara göre kaçak debi karşılaştırması yapılmıştır. Görüldüğü gibi burada artan sıkıştırma sonu basıncı ile kaçak debinin arttığı ve 0,01569465 kg s^{-1} değerine ulaştığı görülmektedir. Artan basınç ile bu değerin artması beklenen ve olağan bir durumdur, ancak bu değerin artışının basınç kaybına neden olduğu da bir gerçektir. Şekil 12' de ise sıkıştırma sonunda, 1B modelden alınan 7,5MPa değeri ve bu değerden daha aşağıda olan basınçlara göre akışkan hızlarının karşılaştırması yapılmıştır. Burada da Şekil 11' e bağlı olarak en yüksek basınç değerinde en yüksek hava hızı hesaplanmaktadır. Şekil 13' de basınçlar karşısında segman yuvasındaki havanın sıcaklık konturları verilmiştir. Kaçak debinin ve dolayısıyla akışkan hızının artmasına bağlı olarak mevcut segman yuvasına birim zamanda daha fazla hava kütlesi girişi olmuştur. Segman yuvasının giriş ve çıkış kesitlerinin oldukça küçük bir kenara sahip olması dolayısıyla akışkan hacmi içerisinde basınç artışı meydana gelmiş ve hava sıcaklığı giriş sıcaklığı olan 2 000 K'den 4 069,244 K'e kadar kısa sürelerde olmak koşuluyla yükselmiştir. Bu sıcaklık artışı da kaçak debilerin artışı gibi beklenen ancak istenmeyen bir durumdur.



Şekil11. Sıkıştırma Basınçlarına Göre Kaçak Debiler



Şekil12. Sıkıştırma Basınçlarına Göre Akışkan Hızları



Şekil13. Sıkıştırma Basınçlarına Sıcaklık Konturları

Sonuç ve Öneriler

Enerji verimliliği ve daha az emisyon salınımı hedefleyen bu çalışma ile literatürdeki konu ile ilgili çalışmalara yeni bir bakış açısı kazandırılmıştır. Literatürdeki segman boşluklarında yer alan ve basınç kaybına neden olan fazla çalışma bulunmamakta ve sızdırmazlık elemanlarının genellikle sürtünme kayıpları incelenmiş durumdadır. Ancak, sıkıştırma ile ateşlemeli motorlardaki yüksek sıkıştırma oranına bağlı olarak elde edilen yüksek basınca engel oluşturabilecek ve verim kaybına neden olabilecek kaçak debiler de motor performansı ve emisyonları için incelemeye değer bölgelerdendir. Bu çalışmada, Renault F-Type F8Q706 motorunun demontajı gerçekleştirilerek, birebir silindir ölçüleri alınmış, piston segman arasındaki akış hacminin geometrisi oluşturulmuştur. Motor ilk olarak 1B olarak modellenmiş ve buradan sıkıştırma sonu sıcaklık ve basınçlar hesaplanmıştır. Bu parametreler, segman yuvası boşluğunun 2B HAD modelinde sınır şartı olarak kullanılmıştır. Ayrıca 1B' den elde edilen basınç değeri olan 7,5 MPa basıncından hariç olarak 5 MPa ve 3 MPa basınçları için de kaçak debiler hesaplanmıştır.

Bu çalışmadan elde edilen sonuçlar, segman yuvasındaki kaçak debi, akışkan hızı ve akışkan sıcaklığı üzerinde farklı modellerin bütünleşik olarak kullanıldığı bir disiplin anlayışı sağlanmıştır. Elde edilen bulgular, motor ve yanma konularında yapılan ilgili mühendislik uygulamalarında segman tasarımı ve optimize edilmesi süreçlerine rehberlik edebilecek potansiyeldedir.

Sonuç olarak, hem 1B model ve test doğrulamaları yapılmış, hem de 2B HAD modeli hassasiyet analizleri yapılmış ve bütünleşik bir yaklaşımla segman yuvasındaki boşlukta bulunan havanın davranışları basınç etkisi altında detaylı bir şekilde incelenmiştir. İnceleme ile berber yüksek sıkıştırma oranlarında basınç kayıplarının ve kaçak debilerin arttığı tespit edilmiştir. Segmanlarda buluna ağız açıklığı ve ağız profillerinin bu durum karşısında direkt olarak belirleyici bir rolü vardır. Bu kaçaklara önlem olarak segman profillerinin yeniden gözden geçirilmesi ve enerji verimliliğinin arttırılması sağlanabilir.

Yazar Katkısı

Hüdagül Değirmenci 2B HAD analizlerinin yapılması ve verilerin elde edilmesini sağladı. *Emrah Kantaroğlu* 1B motor modelinin oluşturulması, 2B HAD analizlerinin sınır şartlarının belirlenmesi ve verilerin sunulmasını gerçekleştirdi. Yazarlar makaleyi birlikte yazdı, okudu ve onayladı.

Etik

Bu makalenin yayınlanmasıyla ilgili herhangi bir etik sorun bulunmamaktadır.

Çıkar Çatışması

Yazarlar herhangi bir çıkar çatışması olmadığını belirtmektedir.

ORCID

Hüdagül Değirmenci https://orcid.org/0009-0003-4795-9243

Emrah Kantaroğlu https://orcid.org/0000-0002-6127-4318

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Arazi Örtüsü ile Kentsel Isı Adası Etkisi Arasındaki İlişki: Ordu Kent Merkezi (Türkiye) Örneği

Mesut Güzel[1], Pervin Yeşil[1]

[1]Ordu Üniversitesi, Ziraat Fakültesi, Peyzaj Mimarlığı Bölümü, Ordu

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Öz

Bu çalışmada, üç temel arazi örtüsü tipi ile Arazi Yüzey Sıcaklığı (AYS) ve Kentsel Isı Adası (KIA) etkisi arasındaki ilişkinin ortaya konulması amaçlanmıştır. Bu amaç doğrultusunda; AYS'nin hesaplanmasında Landsat 8 OLI/TIRS görüntüleri ve arazi örtüsünün sınıflandırılmasında denetimsiz sınıflandırma algoritmaları kullanılmıştır. Elde edilen bulgular istatistiksel yöntemler kullanılarak incelenmiştir. Çalışmanın sonuçları, Karadeniz kıyı kentlerinden biri olan Ordu'da KIA etkisinin ve AYS'nin mekânsal dağılımının arazi örtüsünün tipine göre değiştiğini göstermiştir. AYS ortalaması, yapılaşmış alanlarda bitki örtüsü ile kaplı alanlara göre ortalama 3 °C ve su yüzeylerine göre 8.3 °C daha yüksektir. Kent merkezindeki KIA ve KIA olmayan alanlar arasında ise 4.7 °C'lik sıcaklık farkı bulunmaktadır. Sonuç olarak; KIA etkisinin mekânsal örüntüsü ortaya konulmuş ve Ordu kent merkezi ölçeğinde, iklim değişikliğinin zararlı etkilerine karşı etkili stratejilerin geliştirilmesi noktasında karar vericilere referans sağlanmıştır.

Anahtar Kelimeler: arazi yüzey sıcaklığı, alan kullanımı/arazi örtüsü, kentsel ısı adası etkisi, uzaktan algılama, Landsat 8

Relationship Between Land Cover and Urban Heat Island Effect: The Case of Ordu City Center (Türkiye)

Abstract

This study aims to reveal the relationship between three land cover types and Land Surface Temperature (LST) and Urban Heat Island (UHI) effects. For this purpose, Landsat 8 OLI/TIRS images were used in calculating LST and unsupervised classification algorithms were used in classifying land cover. The findings were examined using statistical methods. The results of the study showed that the spatial distribution of LST and UHI in Ordu, one of the Black Sea coastal cities, varies according to the type of land cover. The mean LST is 3 °C higher in built-up areas than vegetated areas and 8.3 °C higher than in water bodies. There is a temperature difference of 4.7 °C between UHI and non-UHI areas in the city center. As a result; the spatial pattern of the UHI effect was revealed and a reference was provided to decision makers in terms of developing effective strategies against the detrimental effects of global climate change at the Ordu city center.

Keywords: land surface temperature, land use/land cover, urban heat island effect, remote sensing, landsat 8

Sorumlu Yazar / Corresponding Author: Mesut Güzel mesutguzel@odu.edu.tr

Giriş

Birleşmiş Milletler Nüfus Fonu [UNFPA] (2022) tahminlerine göre, dünya nüfusunun 2022 yılına kadar 7.95 milyara yaklaşması ve bu nüfusun yarısından fazlasının kentlerde veya kent yakınlarında yaşaması beklenmektedir. Kentsel nüfusun küresel nüfusa oranının 2040 yılında %80'e, 2050 yılında ise %85'e ulaşması öngörülmektedir (BM, 2019). Bu bilgilere göre, kentlerdeki insan sayısının yaklaşık 2 ila 3 milyar artacağı anlaşılmaktadır (Huang vd., 2019). Dünya nüfusunun çoğunun kentlerde yaşıyor olması ve yapı yoğunluğunun yüksek olması, kentleri iklim değişikliğinden etkilenme riski en yüksek yerler haline getirmektedir (Huq vd., 2007; Singh vd., 2021). Kentsel alanlar, kentsel nüfus arttıkça hızla genişlemektedir. Kentsel alanlar 2001 ile 2018 yılları arasında %168 oranında genişlemiştir (Huang vd., 2021). Kentsel genişlemenin birçok çevresel etkisi vardır ve kentleşme süreçleri doğal alanları önemli ölçüde değiştirmektedir (Girardet, 2020). Kentleşme süreci; yüzey yayınırlığı, albedo ve pürüzlülük gibi arazi yüzeyi özelliklerini değiştirerek arazi yüzeyi ile güneş enerjisi arasındaki dengeyi değiştirir (Kaya, 2018; Grigoras ve Uritescu, 2019). Bu değişen özellikler nedeniyle kentsel iklimler, çevredeki iklim koşullarından farklı, benzersiz özelliklere sahiptir. Jeomorfolojik ve arazi örtüsü özelliklerine bağlı olarak, kentsel ve kırsal alanlar arasındaki sıcaklık farkı 10 °C'ye ulaşabilmektedir (European Environment Agency [EEA], 2012). Manley (1958) bu sıcaklık farkını Kentsel Isı Adası (KIA) etkisi olarak tanımlamıştır.

Kentsel ısı adaları, kentlerde kırsal alanlara kıyasla daha yüksek yüzey ve hava sıcaklıklarının görülmesi ile karakterize edilmektedir (Buyantuyev ve Wu, 2010; Filho vd., 2018; Forman, 2014; Hu vd., 2019; Kleerekoper vd., 2012; Song vd., 2014; Tromeur vd., 2012). Araştırmalar; yoğun kentsel alanların ve çıplak arazilerin KIA etkilerini artırdığını, kentsel yeşil alanların, ormanların ve su kütlelerinin ise bunları azalttığını göstermektedir (Amiri vd., 2009; Grigoras ve Uritescu, 2019). Bu durum, arazi örtüsü ile KIA etkisi arasındaki karmaşık ilişkinin hem bölgesel hem de yerel düzeylerde analiz edilmesini gerektirmektedir. Bu nedenle, KIA etkisi ile arazi kullanımı/arazi örtüsü (AK/AÖ) arasındaki ilişki kapsamlı bir şekilde araştırılmıştır. Du ve arkadaşları (2020) tarafından yürütülen bir araştırmada; hızlı kentleşmenin KIA etkisinin mekânsal ve zamansal örüntüleri üzerindeki etkisi analiz edilmiş ve kentleşmenin KIA etkisine katkıda bulunduğu gösterilmiştir. Dolayısıyla; AK/AÖ değişimi ile AYS arasındaki ilişkiyi karakterize eden araştırmalar, bu dinamiklerin anlaşılmasının kentsel planlama ve etkili politikaların geliştirilmesi noktasında oldukça önemlidir (Tran vd., 2017).

Bu çalışmada, arazi örtüsü tipleri ile KIA etkisi arasındaki ilişkinin ortaya konulması, KIA etkisindeki alanların mekânsal dağılımının haritalandırılması ve kent merkezindeki mahalleler arasındaki AYS farklılıkların incelenmesi amaçlanmıştır. Bu amaç doğrultusunda; uzaktan algılama verileri, denetimsiz sınıflandırma algoritmaları ve istatistiksel değerlendirme yöntemleri kullanılmıştır. Henüz kentleşme sürecinde olan Ordu kentinde, iklim değişikliğine uyumu destekleyen adımların atılması gerekmektedir. Bu çalışma, yakın gelecekte Ordu kent merkezinde yapılacak birçok benzer çalışma için referans noktası olacaktır. Araştırma bulgularının, Ordu kentindeki iklim değişikliğine uyum süreçlerine rehberlik etmesi, kentteki ısı adalarını azaltmak için etkili stratejilerin geliştirilmesine katkıda bulunması ve sürdürülebilir kalkınma hedeflerinin gerçekleştirilmesine yardımcı olması beklenmektedir.

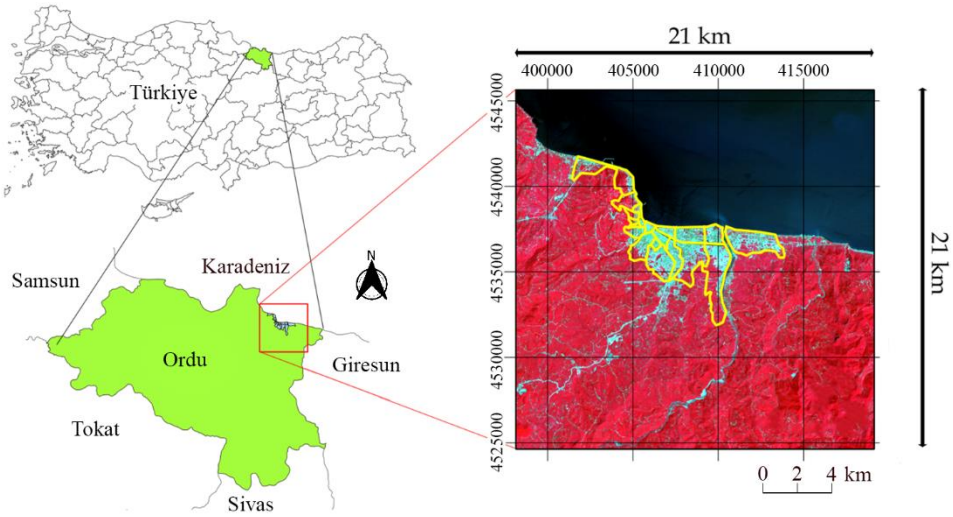
Materyal ve Yöntem

Çalışma Alanı

Ordu, Türkiye'nin Karadeniz kıyısındaki kentlerinden biridir. Şehir hızla kentleşmektedir ve kentsel nüfus her geçen yıl artmaktadır. 2022 yılı itibariyle kent merkezinde 185 096 kişi yaşamaktadır ve nüfus yoğunluğu 545 kişi/km^2'dir (TÜİK, 2023). 1990-2018 yılları arasındaki 28 yıllık dönemde, Ordu ilinde kentsel dokuyu da içeren yapay yüzeylerin alanı %92 oranında artmıştır (Yeşil ve Güzel, 2021). Günümüzde de yapılaşmanın ve yeni yerleşimlerin oranı artmaya devam etmektedir. Özellikle Ordu Üniversitesi'nin merkez yerleşkesinin bulunduğu ve Ordu Şehir Hastanesi'nin inşa edilmekte olduğu Cumhuriyet Mahallesi en yoğun kentleşmenin görüldüğü mahalledir. Kent merkezini oluşturan mahalleler, yapılaşmış alan ve bitki örtüsü oranları bakımından çok farklı karakter taşımaktadır.

Güzelyalı, Kirazlimanı ve Karapınar mahallelerinde bitki örtüsünün yoğun olduğu bölgeler ağırlıkta iken Yeni, Subaşı ve Düz mahallelerinde bitki örtüsü oranı oldukça düşüktür.

Ordu kent merkezi için yıllık ortalama sıcaklık 14.5 °C olup, yıllık yağış miktarı 1064.4 mm'ye ulaşmaktadır (MGM, 2022). En yüksek ortalama sıcaklığa sahip ay 23.4 °C ile Ağustos'tur. En yüksek yağışa sahip ay ise Ekim'dir (131 mm). Thornthwaite (1948) iklim sınıflandırma sistemine göre kentin iklim sınıfı B2, B'2, s, b'4'tür (B2: Nemli, B'2: 2. derece mezotermal, s: Orta yaz açığı, b'4: Yaz buharlaşması: %50.5). Çalışma alanı olarak; Ordu kent merkezi ve çevresinin de dâhil olduğu 21 km x 21 km'lik bir alan ve kent merkezini oluşturan 21 mahalle seçilmiştir (Şekil 1). Ordu ilinin kuzeydoğusunda yer alan araştırma alanında yükseklik deniz seviyesinden başlayarak 1125 m'ye kadar çıkmaktadır. İlk olarak; Ordu kent merkezi ve yakın çevresine karşılık gelen bölge için arazi örtüsü ve AYS arasındaki ilişki değerlendirilmiş ardından 21 mahalle özelinde kent merkezine odaklanılmıştır.



Şekil 1. Ordu Kent Merkezinin Konumu ve Kent Merkezini Oluşturan Mahalleler

Yöntem

Veriler ve Görüntü İşleme

Çalışmada hem spektral indeksler hem de AYS hesaplanacağından, Operasyonel Arazi Görüntüleyici (OLI) ve Termal Kızılötesi Sensör (TIRS) algılama araçlarını bir arada içeren ve değerlendirme için yeterli mekânsal çözünürlüğe (30 m) sahip Landsat 8 görüntüleri tercih edilmiştir. Söz konusu görüntüler, USGS Earth Explorer web sitesinden (https://earthexplorer.usgs.gov) ücretsiz şekilde indirilmiştir.

Çalışmada kullanılmak üzere 5 Haziran 2020'de yerel saatle 11.07'de (UTC+3) çekilen bir Landsat 8 görüntüsü seçilmiştir (Tablo 1). Tüm görüntü için bulut örtüsü %9 olmasına rağmen, çalışma alanı sınırına göre kırpılan görüntü tamamen bulutsuzdur. Uydu görüntüsünün kalitesini iyileştirmek ve görüntüdeki olumsuz etkileri ortadan kaldırmak için geometrik ve radyometrik düzeltmeler uygulanmıştır. Çalışmada kullanılan termal kızılötesi bandın (TIRS-bant 10) mekânsal çözünürlüğü 100 m olduğundan, optik bantların çözünürlüğünü (30 m) eşitlemek için en yakın komşu algoritması ile yeniden örnekleme yapılmıştır.

Tablo 1. Çalışmada Kullanılan Uydu Görüntüsüne İlişkin Bilgiler

Görüntü tarihi ve saati	Uydu ve sensör	Mekânsal çözünürlük (m)	Bulutluluk (%)
05.06.2020 - 08.07 (UTC)	Landsat-8 OLI/TIRS	30	9

Spektral İndekslerin Hesaplanması

Sınıflandırmada kullanılmak üzere, arazi örtüsü sınıflarının spektral özelliklerinden yararlanan birçok indeksten yararlanılmıştır. Denetimsiz sınıflandırma sürecinde girdi verisi olarak kullanılan spektral

indeksler Tablo 2'de gösterilmiştir. Bu indeksler, Landsat 8 uydusu üzerindeki OLI (Operational Land Imager) modülü tarafından sağlanan R, G, B, NIR ve SWIR gibi bantların çeşitli eşitliklere göre oranlanmasıyla elde edilmektedir. Bu indeksler arasında, oranlamayla elde edilen diğer iki endeksteki (NDVI ve NDBI) matematiksel farkla yalnızca BUI (Built-up Index) hesaplanır. Çalışmada bitki örtüsünü ön plana çıkaran 5 adet bitki örtüsü indeksi (DVI, NDVI, IPVI, WDVI, SAVI), yapılaşmış alanları belirlemede kullanılan 5 adet yapılaşma indeksi (NBI, NDBI, BAEI, BUI, UI) ve 5 adet su yüzeyi indeksi (NDWI-1, NDWI-2, MNDWI, AWEI, WRI) QGIS 3.16.6 yazılımında yer alan "Raster Calculator" aracı ile hesaplanmıştır. Her bir indeksin haritası bir sonraki adımda gerçekleştirilen denetimsiz sınıflandırmada girdi verisi olarak tanımlanmıştır.

Tablo 2. Çalışmada Kullanılan Spektral İndeksler ve Formülleri

İndeks	Eşitlik	Kaynak
DVI	$\rho_{NIR} - \rho_R$	Lillesand vd. (2015)
NDVI	$(\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R)$	Tucker (1979)
IPVI	$\rho_{NIR}/(\rho_{NIR} + \rho_R)$	Crippen (1990)
WDVI	$\rho_{NIR} - 0.96916 \times \rho_R$	Qi vd. (1994)
SAVI	$(\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R + 0.5) \times (1 + 0.5)$	Huete (1988)
NBI	$(\rho_{SWIR} \times \rho_R)/\rho_{NIR}$	Jieli vd. (2010)
NDBI	$(\rho_{SWIR} - \rho_{NIR})/(\rho_{SWIR} + \rho_{NIR})$	Zha vd. (2003)
BAEI	$(\rho_R + 0.3)/(\rho_G + \rho_{SWIR})$	Bouzekri vd. (2015)
BUI	$NDBI - NDVI$	He vd. (2010)
UI	$((\rho_{SWIR} - \rho_{NIR})/(\rho_{SWIR} + \rho_{NIR}) + 1) \times 100$	Kawamura vd. (1996)
NDWI-1	$(\rho_{NIR} - \rho_{SWIR})/(\rho_{NIR} + \rho_{SWIR})$	Gao (1995)
NDWI-2	$(\rho_G - \rho_{NIR})/(\rho_G + \rho_{NIR})$	McFeeters (1996)
MNDWI	$(\rho_G - \rho_{SWIR})/(\rho_G + \rho_{SWIR})$	Xu (2006)
AWEI	$4 \times (\rho_G - \rho_{SWIR2}) - (0.25 \times \rho_{NIR} + 2.75 \times \rho_{SWIR1})$	Mustafa vd. (2017)
WRI	$(\rho_G + \rho_R)/(\rho_{NIR} + \rho_{SWIR1})$	Shen ve Li (2010)

Arazi Örtüsünün Denetimsiz Sınıflandırma ile Elde Edilmesi

AYS'nin farklı arazi örtülerine göre değişimini belirlemek için öncelikle çalışma alanındaki arazi sınıflandırılmalıdır. Arazi örtüsü sınıflandırmaları, denetimli ve denetimsiz sınıflandırma yöntemleri ile yapılabilmektedir. Ancak denetimsiz sınıflandırma yöntemleri zaman ve maliyet açısından daha avantajlıdır. Denetimli sınıflandırma algoritmalarında çalışma alanı hakkında ön bilgi sahibi olmanız gerekirken, denetimsiz algoritmalarda böyle bir gereklilik bulunmamaktadır (Mohammady vd., 2015). Bu çalışmada arazi örtüsü sınıflandırması için denetimsiz sınıflandırma algoritmaları olarak K-ortalamalar ve ISODATA kullanılmıştır. Her iki algoritma da tek tek veya bir arada Landsat 8 OLI/TIRS görüntülerinin denetimsiz sınıflandırılmasında başarıyla uygulanmıştır (Herbei vd., 2015; Mohamed, 2021; Taufik vd., 2019; Yilmaz vd., 2023). Bu algoritmalar temelde kümeleme algoritmalarıdır. Kümeleme algoritmaları, benzer spektral özelliklere sahip nesneleri (bu makalede nesneler piksellerdir) aynı kümede gruplandırma işlemleridir. Kümeleme algoritması olarak K-ortalamalar, verileri önceden tanımlanmış merkez noktaları ile veri nesnesi arasındaki mesafeye göre k kümeye ayırır (Rajab ve George, 2021). ISODATA algoritmasının arkasındaki mantık K-ortalamalara benzese de, K-ortalamalar algoritmasının aksine, küme sayısı işlemden önce ayarlanmaz. Bu sınıf sayısı her yineleme boyunca aynı tutulurken, uygun sınıf numarası ISODATA algoritmasında istatistiksel olarak benzer özelliklere sahip kümeleri birleştirerek veya bölerek otomatik olarak belirlenmektedir (Abbas vd., 2016; Rajab ve George, 2021).

Sınıflandırma, açık kaynaklı bir CBS yazılımı olan QGIS 3.16.6 ile uyumlu olan Yarı Otomatik Sınıflandırma Eklentisi (SCP) kullanılarak gerçekleştirilmiştir (Congedo, 2021). Python tabanlı bir eklenti olan SCP; Landsat, MODIS ve Sentinel gibi popüler uydulardan gelen görüntülerin indirilmesini ve işlenmesini sağlar. SCP eklentisi, etkinliği ve doğruluğu ile tanınan K-ortalamalar ve ISODATA

algoritmalarını kullanarak pratik görüntü sınıflandırmasına olanak tanımaktadır. Bu nedenle, bu çalışmada sınıflandırma her iki algoritma ile de yapılmış ve sonuçlar en doğru yöntem seçilerek yorumlanmıştır. Araştırmanın birincil amacı; inşa edilmiş çevreler, bitki örtülü alanlar ve su kütleleri arasındaki AYS değerlerindeki farklılıkları değerlendirmektir. Bu nedenle, istenen sınıf sayısı 3 olarak belirlenmiş ve sınıflandırma süreci maksimum 10 yineleme ile gerçekleştirilmiştir.

Sınıflandırma Doğruluğunun Belirlenmesi

Bu çalışmada gerçekleştirilen denetimsiz sınıflandırmanın doğruluğunu değerlendirmek için hata matrisi kullanılarak bir doğruluk değerlendirmesi yapılmıştır. Hata matrisi, sınıflandırma sonuçlarının referans verilerle karşılaştırılmasını kolaylaştıran satır ve sütunların tablo biçiminde düzenlenmesinden oluşur. Bu matris, sınıflandırma doğruluğunun değerlendirilmesini sağlamakla birlikte hataları kategorilere ayırarak sınıflandırma modelinin tahmin yeteneklerini artırır (Stehman, 2009). Hata matrisi kullanılarak denetimli veya denetimsiz sınıflandırma algoritmalarının performansı nicel olarak ölçülebilmektedir. Ayrıca, hata matrisi temelinde hesaplanan doğruluk göstergelerinin yardımıyla sınıflandırma algoritmaları arasında birden fazla karşılaştırma yapılabilirken, en yüksek doğruluğa sahip algoritma da bu yolla seçilebilmektedir.

Sınıflandırma doğruluğunu belirlemede, referans veri olarak kullanılacak yeterli kontrol noktasının belirlenmesi önem arz etmektedir. Denetimsiz sınıflandırmanın doğruluğunu test etmek için, bu çalışmada önceki benzer çalışmalarda tercih edilen 200 adet yer kontrol noktası yeterli kabul edilmiştir (Ismail ve Jusoff, 2008; Talukdar vd., 2020). Sınıfların alan büyüklüğüne göre tabakalı rastgele örnekleme yoluyla 3 arazi örtüsü sınıfına atanmıştır. Buna göre; 200 kontrol noktasından 24'ü yapılaşmış alana, 115'i bitki örtüsüne ve 61'i su yüzeyi sınıflarına karşılık gelmiştir. Yüksek çözünürlüklü ve uygun zaman aralığına sahip Google Earth Pro görüntüleri değerlendirme için referans verisi olarak kullanılmıştır. Sınıflandırma sonucunda arazi sınıfının atandığı noktanın gerçek arazi sınıfı Google Earth Pro yazılımı kullanılarak kontrol edilmiştir. Bu işlem her kontrol noktası için tekrarlanarak bir hata matrisi oluşturulmuştur. Hata matrisinin geliştirilmesinin ardından, her iki sınıflandırma algoritması için üretici ve kullanıcı doğruluğu, genel doğruluk ve kappa istatistikleri hesaplanmıştır (Congalton ve Green, 2019; Olofsson vd., 2014). Genel doğruluk, sınıflandırma sonucunda doğru tespit edilen nokta sayısının toplam nokta sayısına oranının yüzdesidir. Arazi sınıfları ölçeğinde sınıflandırma doğruluğu, üretici ve kullanıcı doğruluğu kullanılarak değerlendirilmiştir. Üretici doğruluğu, referans verilere göre bir arazi örtüsü sınıfı içinde doğru sınıflandırılan noktaların o arazi örtüsü sınıfındaki toplam nokta sayısına oranı olarak tanımlanır. Sınıflandırma veya harita veri kümelerinden türetilen kullanıcı doğruluğu, bir sınıf içinde doğru tespit edilen noktaların o arazi sınıfındaki toplam nokta sayısına oranı olarak hesaplanmaktadır (Everitt vd., 2008). Kappa değeri, bir sınıflandırma sürecinin sonuçları ile referans veriler arasındaki eşleşme düzeyinin istatistiksel bir göstergesidir (Talukdar vd., 2020). %80'in üzerindeki bir kappa istatistik değeri, sınıflandırma sonuçları ile gerçek referanslı veriler arasında sağlam bir uyuma işaret eder (Jensen, 2015). Kappa istatistiği aşağıdaki formül kullanılarak hesaplanmıştır.

$$\widehat{K} = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{k}(x_{i+} * x_{+j})}{N^2 - \sum_{i=1}^{k}(x_{i+} * x_{+j})} \quad (1)$$

Burada N, toplam referans noktası sayısı; k, hata matrisindeki arazi sınıflarını gösteren satır sayısı; x_{ii}, satır i ve sütun i için doğru sınıflandırılan nokta sayısı; x_{i+} ve x_{+j}, sırasıyla satır i ve sütun j'deki toplam gözlem sayılarıdır.

Arazi Yüzey Sıcaklığı (AYS) Haritasının Oluşturulması

AYS, KIA etkisinin incelemesinde oldukça önemli bir parametredir. Radyometrik sıcaklık olarak da adlandırılan AYS, Dünya yüzeyinin sıcaklığını belirtmektedir (Almeida vd., 2021). Bu ölçüm genellikle uydu platformlarına yerleştirilen termal kızılötesi sensörlerle yapılmaktadır (Stewart ve Mills, 2021). Uzaktan algılama verilerinden, Dünya yüzeyinin radyatif özelliklerini belirlemek için kullanılabilen AYS'yi hesaplamak mümkündür (Almeida vd., 2021). Dahası, bu coğrafi olarak referanslanmış verilerin

çoğuna serbestçe erişilebilmektedir (Stewart ve Mills, 2021). Kızılötesi uzaktan algılama görüntülerinden türetilen AYS haritaları, KIA etkisinin mekânsal dağılımını ve kentsel yüzey özellikleriyle ilişkisini incelemek için yaygın olarak uygulanmaktadır (Algretawee vd., 2019; Chen ve Zhang, 2017; Gui vd., 2019; Sfîcă vd., 2023). AYS'nin uygulama alanı KIA çalışmalarıyla sınırlı değildir. AYS, küresel iklim değişikliği (Pandey vd., 2022; Zou vd., 2020), kriyosfer erimesi (Fang vd., 2023; Zhong vd., 2020;) ve böcek istilası (Farrah vd., 2017) gibi birçok farklı alanda kullanılmaktadır.

AYS, Landsat-8'deki termal bant (TIRS-1) kullanılarak elde edilmiştir. Landsat uydusundan elde edilen görüntülerin biçimi Dijital Sayılar (DN) formatındadır. Bu nedenle, AYS'yi hesaplamak için yaygın olarak kullanılan aşağıdaki algoritma izlenmiştir (Artis ve Carnahan, 1982). İlk adım, termal banttaki dijital sayıları Atmosfer Üstü (TOA) spektral parlaklık değerine dönüştürmektir (USGS, 2013):

$$L_\lambda = M_L \times Q_{cal} + A_L \quad (2)$$

Burada L_λ, W m^{-2} s r^{-1} mm^{-1} cinsinden spektral parlaklıktır; M_L, bant 10 için çarpımsal ölçekleme faktörüdür (0.0003342); A_L ise, bant 10 için eklemeli ölçekleme faktörüdür (0.1).

İkinci adım, spektral parlaklık değerini (L_λ) Parlaklık Sıcaklığı (T_B) değerine dönüştürmektir:

$$T_B = K_2/(\ln(K_1/L_\lambda + 1)) - 273.15 \quad (3)$$

T_B, uydu seviyesindeki parlaklık sıcaklığını; K_1 ve K_2 ise, Landsat 8'deki bant 10 için termal dönüşüm sağlamak için kullanılan sabitleri temsil etmektedir. Landsat 8 OLI/TIRS için K_1, 774.89 ve K_2, 1321.08'dir. T_B değerini kelvinden santigrata dönüştürmek için 273.15 çıkarılmıştır.

Üçüncü adım, yayınırlık (ε) değerinin hesaplanmasını içermektedir. Bunun için, bitki örtüsü oranına dayalı bir yaklaşım benimsenmiştir (Carlson ve Ripley, 1997). Yayınırlık (emisivite), P_v ve aşağıdaki eşitlik kullanılarak hesaplanır:

$$\varepsilon = 0.004 \times P_v + 0.986 \quad (4)$$

P_v, bitki örtüsü oranı olup, aşağıdaki eşitlik kullanılarak hesaplanmıştır:

$$P_v = [(NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})]^2 \quad (5)$$

Burada $NDVI_{min}$, çalışma alanının minimum NDVI değeri ve $NDVI_{max}$, çalışma alanının maksimum NDVI değeridir. NDVI, Eşitlik 6'daki matematiksel işlemle hesaplanmıştır (Guha vd., 2018; Kumar vd., 2022):

$$NDVI = (\rho_{NIR} - \rho_R)/(\rho_{NIR} + \rho_R) \quad (6)$$

ρ_{NIR} yakın kızılötesi bant (Landsat 8 için bant 5) ve ρ_R kırmızı bandı göstermektedir (Landsat 8 için bant 4). NDVI değerleri - 1 ile 1 arasında değişmektedir. Genel olarak, NDVI değerleri su kütleleri için sıfırın altındadır. Ancak; çayırlar, çalılar, otlar ve ormanlar dahil olmak üzere tüm bitki örtüsü için pozitiftir (Jones ve Vaughan, 2010). Yoğun ve sağlıklı bitki örtüsü yüksek NDVI değerleri ile karakterize edilmektedir.

Son olarak; AYS, T_B ve emisivite (ε) değerleri kullanılarak hesaplanmıştır (Weng vd., 2004; Guha vd., 2018):

$$LST = T_B/[1 + (\lambda \times T_B/\rho) \times ln\varepsilon] \quad (7)$$

Burada; AYS, Celcius (°C) cinsinden arazi yüzeyinin sıcaklığını temsil etmektedir. λ, dalga boyunu (bant 10 için 10.9 mm), ε, yüzey emisivitesini; k, Boltzman sabitini (1.38×10^{-23} J K^{-1}); ρ, 1.438×10^{-2} m K değerini; c, ışık hızını (2.998×108 m s^{-1}) ve h, Planck sabitini (6.626×10^{-34} J s) ifade etmektedir.

KIA Etkisinde Olan ve KIA Etkisinde Olmayan Alanların Çıkarılması

KIA ve KIA olmayan alanları belirlemek için bir eşik değeri hesaplanmıştır (Guha vd., 2017; Guha vd., 2018; Ma vd., 2010). Eşik değerini hesaplamak için ortalama AYS değeri (Eşitlik 8) ve standart sapma (Eşitlik 9) değerlerinin bilinmesi gerekmektedir.

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} \quad (8)$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i-\mu)^2}{N}} \quad (9)$$

Burada x_i, piksel i'nin °C cinsinden AYS değeri, N çalışma alanındaki toplam piksel sayısı, μ çalışma alanının ortalama AYS değeri, σ çalışma alanındaki AYS değerlerinin standart sapmasıdır. Ortalama AYS değerinin yarısı (μ) ile çalışma alanındaki standart sapmanın (σ) toplamı eşik değerini vermektedie. Bir pikselin AYS değeri eşik değerinden büyükse, o piksel KIA etkisinde alan olarak tanımlanmıştır (Eşitlik 10). Tersi şekilde, pikselin AYS değeri eşik değerine eşit veya altındaysa, o piksel KIA etkisinde olmayan bir alan olduğu anlaşılmaktadır (Eşitlik 11). Bu işlem tüm çalışma alanı için tekrarlandığında, KIA ve KIA olmayan alanların haritası elde edilmiştir.

$$LST > \mu + 0.5 * \sigma \quad (10)$$

$$0 < LST \leq \mu + 0.5 * \sigma \quad (11)$$

İstatistiksel Analiz

Arazi örtüsü çeşitleri ve mahalleler arasındaki ortalama AYS'deki farklılıklar istatistiksel yöntemler kullanılarak analiz edilmiştir. Farklı arazi örtüsü tipleriyle ilişkili olarak ortalama AYS'deki farklılaşma durumu istatistikse tek yönlü varyans analizi (ANOVA) ile test edilmiştir (Stathopoulou vd., 2007; Li vd., 2014). Kent merkezindeki 21 mahallenin ortalama AYS'leri arasındaki fark aynı yöntem kullanılarak istatistiksel olarak değerlendirilmiştir. Ancak bu analizi gerçekleştirmek için öncelikle normallik ve varyans homojenliği gibi varsayımlar test edilmiştir (Jackson ve Ferguson, 1972). Verilerin normalliğini kontrol etmek için Shapiro-Wilk testinden yararlanılmıştır (Shapiro ve Wilk, 1965). Varyansların homojenliği Levene testi ile değerlendirilmiştir (Levene, 1960). Üç ya da daha fazla grup için ortalamalar karşılaştırılmak istendiğinde verilerin normal dağılıp dağılmadığına göre parametrik ya da parametrik olmayan testler tercih edilmektedir. Bu çalışmada her iki gruba ait veriler normal dağıldığı için ANOVA testi tercih edilmiştir. Ancak bu ön koşul mevcut değilse bu analiz ancak Kruskal-Wallis (Kruskal ve Wallis, 1952) gibi parametrik olmayan bir yöntemle yapılabilmektedir. Varyans analizi grup ortalamalarındaki farkı ortaya koymasına rağmen, ikili karşılaştırmalarda post-hoc testler kullanılmaktadır. Bu noktada uygun testin seçimi varyansların homojenliğine bağlıdır. Levene testi sonucunda veri seti için varyansların homojen dağıldığı görülmüştür. Bu nedenle ikili karşılaştırmalarda Tukey HSD (a=0.05) kullanılmıştır (Tukey, 1949). Tukey testindeki anlamlılık düzeyi farklı araştırmacılar tarafından farklı değerlerde alınabilse de birçok çalışmada yaygın olarak kabul görmüş bir düzey olduğundan, bu çalışmada %5 düzeyi tercih edilmiştir. Tukey testi sonucunda anlamlı olarak farklı olduğu bulunan gruplar sembolize edilmiş ve küçük harflerle işaretlenmiştir.

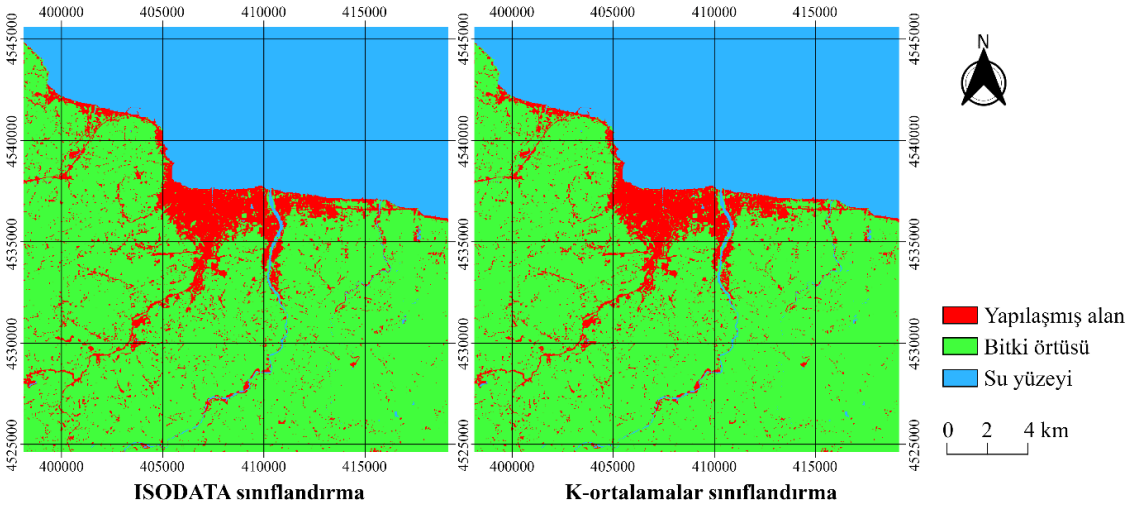
Son olarak, KIA ve KIA olmayan alanlar arasındaki AYS farkını tespit etmek için bağımsız örneklem t-testi kullanılmıştır (Ross ve Willson, 2017). ANOVA testinin aksine, bu test için iki bağımsız grubun olması yeterlidir. Bu çalışma için gruplar KIA ve KIA olmayan bölgelerdir. Bu iki grup arasındaki AYS ortalamasındaki farkın düzeyi ve bu farkın istatistiksel olarak anlamlı olup olmadığı bağımsız örneklem t-testi (a=0.05) ile ortaya çıkarılmıştır. Verilerin normal dağılım göstermediği bir durumda, t-testinin parametrik olmayan eşdeğeri olan Mann-Whitney U testi, iki grubun ortalamalarını karşılaştırmak için kullanılmaktadır (McKnight ve Najab, 2010). T-testi sonucunda iki grup arasındaki fark istatistiksel olarak anlamlı çıkarsa, grup ortalamaları farkı, KIA bölgesi ile KIA bölgesi olmayan bölgeler arasındaki yüzey sıcaklığı farkını vermektedir.

Bulgular ve Tartışma

K-ortalamalar ve ISODATA algoritmaları ile gerçekleştirilen sınıflandırmanın sonuçları Şekil 2'de verilmiştir. Denetimsiz sınıflandırmaların doğruluğunu test etmek için kappa katsayısı ve genel doğruluk hesaplanarak değerler Tablo 3'te gösterilmiştir. ISODATA sınıflandırma sonuçlarına göre üretici ve kullanıcı doğruluğu su yüzeyleri sınıfı için %100'dür. Yapılaşmış alanları temsil eden 24 kontrol noktasından 23'ü doğru tahmin edilmiştir; dolayısıyla bu sınıf için üretici doğruluğu %95.8'dir. Bitki örtüsü için üretici doğruluğu ise %98.3 olarak hesaplanmıştır. Bitki örtüsü sınıfında iki kontrol noktası yanlış tahmin edilerek yapılaşmış alan sınıfına atanmıştır. Su yüzeylerinin tahmininde hata yapmayan

algoritma, yapılaşmış alanlar ve bitki örtüsü sınıflarında kabul edilebilir sınırlar içinde hata göstermiştir. K-ortalamalar algoritması ile oluşturulan arazi sınıflarının hata düzeyi ISODATA algoritmasınınkine benzerdir. Yapılaşmış alanlar için üretici doğruluğu %91.7 iken, bitki örtüsü için %99.1'dir. Sonuç olarak, arazi örtüsü sınıflandırması için genel doğruluk değeri ve kappa katsayısının her iki sınıflandırma yöntemi için de eşit olduğu görülmüştür. Genel doğruluk %98.5 ve kappa istatistiği 0.973'tür. Genel doğruluk düzeyi %90'ın üzerinde ve kappa istatistiği 0.8'in üzerindeyse, sınıflandırılmış görüntü ile gerçek veriler arasında güçlü bir eşleşme olduğu anlaşılmaktadır (Jensen, 2015). Bu nedenle, iki yöntem kullanılarak elde edilen sınıflandırma haritasının da isabetli sonuç verdiği görülmüştür.

Tablo 4'te iki sınıflandırma algoritması ile elde edilen arazi örtüsü alanları hektar ve yüzde olarak gösterilmiştir. Çalışma alanı 21 km x 21 km büyüklüğünde olduğundan toplam alan 44.100 hektardır. ISODATA algoritması ile elde edilen arazi örtüsü haritasına göre yapılaşmış alanlar çalışma alanının %8.8'ini oluştururken, K-ortalamalar algoritmasına göre bu oran %7.9'dur. Bitki örtüsü ile kaplı alanların oranı ISODATA algoritmasına göre %58.6 iken K-ortalamalar algoritmasına göre %59.5'tir. Su yüzeyi ile kaplı alanların oranı her iki sınıflandırma algoritmasına göre çalışma alanının %32.6'sına karşılık gelmektedir.



Şekil 2. ISODATA ve K-ortalamalar Sınıflandırmanın Sonuçları

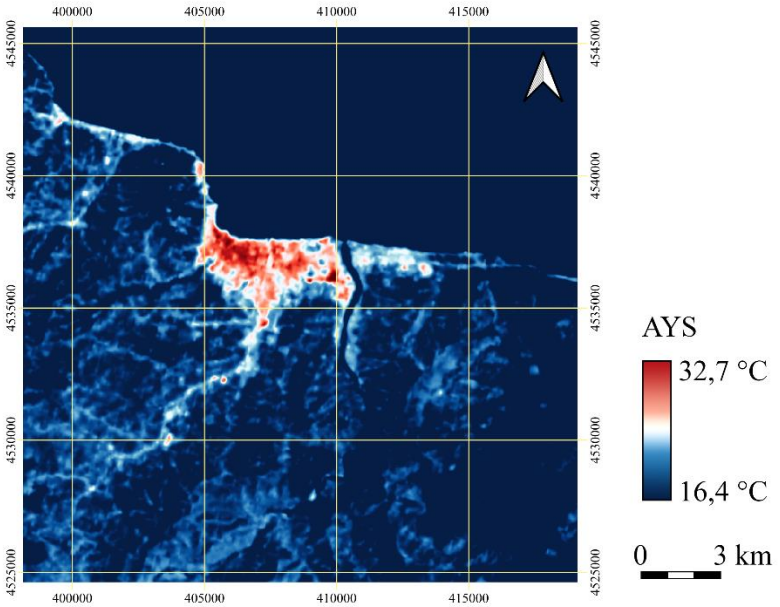
Tablo 3. ISODATA ve K-ortalamalar Sınıflandırmaya İlişkin Hata Matrisi

Sınıflandırılmış veri		Referans Veri					
		Yapılaşmış a.	Bitki ö.	Su y.	Satır toplamı	Üretici doğr. (%)	Kullanıcı doğr. (%)
ISODATA	Yapılaşmış alan	23	2	0	25	95.8	92.0
	Bitki örtüsü	1	113	0	114	98.3	99.1
	Su yüzeyi	0	0	61	61	100.0	100.0
	Sütun toplamı	24	115	61	200		
	Genel doğruluk (%)		98.5				
	Kappa istatistiği		0.973				
Sınıflandırılmış veri		Referans Veri					
		Yapılaşmış a.	Bitki ö.	Su y.	Satır toplamı	Üretici doğr. (%)	Kullanıcı doğr. (%)
K-ortalamalar	Yapılaşmış alan	22	1	0	23	91.7	95.7
	Bitki örtüsü	2	114	0	116	99.1	98.3
	Su yüzeyi	0	0	61	61	100.0	100
	Sütun toplamı	24	115	61	200		
	Genel doğruluk (%)		98.5				
	Kappa istatistiği		0.973				

Tablo 4. Arazi Örtüsü Tiplerinin Alansal Ve Oransal Büyüklükleri

Sınıflandırma	Yapılaşmış alan		Bitki örtüsü		Su yüzeyi		Toplam	
	ha	%	ha	%	ha	%	ha	%
ISODATA	3 880.8	8.8	25 842.6	58.6	14 376.6	32.6	44 100	100.0
K-ortalamalar	3 483.9	7.9	26 239.5	59.5	14 376.6	32.6	44 100	100.0

Çalışma alanı ölçeğinde AYS'nin mekânsal dağılım deseni Şekil 3'te gösterilmiştir. Kırmızı tonlarındaki alanlar yüksek AYS değerini, mavi renk tonundaki alanlar ise nispeten düşük AYS değerlerini göstermektedir. Çalışma alanındaki AYS değeri 16.4 °C ile 32.7 °C arasında değişmektedir. Arazi örtüsü (Şekil 2) ve AYS haritası (Şekil 3) dikkate alındığında, en yüksek yüzey sıcaklıklarının büyük ölçüde yerleşim alanlarıyla örtüştüğü görülmektedir.



Şekil 3. Çalışma Alanının AYS Haritası (21 km x 21 km)

Tek yönlü varyans analizine göre, üç arazi sınıfı (yapılaşmış alan, bitki örtüsü, su yüzeyi) arasında AYS açısından istatistiksel olarak anlamlı bir fark vardır (Tablo 5). Varyansların homojen olması nedeniyle, hangi sınıfların birbirinden farklı olduğunu belirlemek için çift yönlü karşılaştırma testi olan Tukey's HSD kullanılmıştır. Tablo 5'te, AYS ortalamalarının yanındaki küçük harfler farklı grupları göstermektedir. Dolayısıyla, üç arazi sınıfı AYS ortalamaları açısından birbirinden farklıdır. Çalışma alanındaki yapılaşmış alanlarda, ortalama AYS; bitki örtüsünden 3 °C daha yüksektir. En düşük AYS ortalamasına sahip arazi sınıfı, 17.3 °C ile su yüzeyleridir. Çalışma alanında, en yüksek AYS değeri (32.7 °C) yapılaşmış alanlarda gözlenirken, en düşük AYS değeri ise 16.4 °C ile su yüzeyindedir (Tablo 5). Konuyla ilgili yapılan çalışmalarda, bu üç temel arazi örtüsü için ortalama AYS değerlerinin yüksekten düşüğe doğru yapılaşmış alanlar, bitki örtüsü ile kaplı alanlar ve su yüzeyleri olarak sıralandığı konusunda fikir birliği bulunmaktadır. Ayrıca, Çin'in Guangzhou kentindeki yerleşim alanlarındaki ortalama AYS'nin orman alanından ve su kütlelerinden daha yüksek olduğu bildirilmiştir (Sun vd., 2012). İran'ın Maraqeh kentinde yürütülen bir başka çalışmada ise kentsel alanlardaki ortalama AYS değerinin 33.7 °C olarak bulunmuş olup, bu değer su kütlelerindeki ve otlaklar ile meyve bahçeleri gibi bitki örtüsü ile kaplı alanlardaki ortalama AYS değerinden daha yüksektir (Feizizadeh vd., 2013).

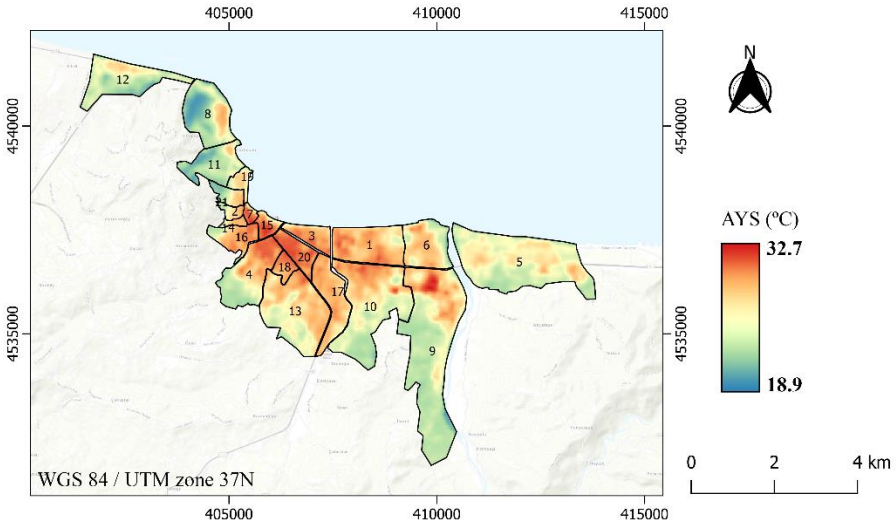
Bu araştırmanın odaklandığı bölgenin topoğrafik özellikleri, AYS ile arazi örtüsü tipi arasındaki ilişkiyi etkileyen ana faktörlerdir. Çin'in Hangzhou kentinde yürütülen bir çalışmanın sonuçları; yükseklik, eğim, bakı ve rölyef özelliklerinin AYS ile güçlü bir şekilde ilişkili olduğunu ortaya koymuştur (Peng vd., 2020). Yükseklik ve AYS arasında genellikle negatif bir korelasyon bulunduğundan AYS değerlerinin yükseklikle birlikte azalması beklenir (Peng vd., 2020; Stroppiana vd., 2014; Ullah vd., 2023). Bununla

birlikte, Maraqeh kentinde yapılan çalışmanın sonuçları bunun tersini göstermektedir. Çalışmada, düşük rakımlı taşkın ovalarında daha düşük AYS değerleri gözlemlenirken, yükseklik arttıkça kayalık ve çıplak toprakla kaplı alanların artması sonucunda AYS değerlerinde önemli artışlar meydana gelmiştir (Feizizadeh vd., 2013).

Tablo 5. Arazi örtüsü tipleri arasındaki ortalama AYS bakımından farklılıklar

	Sınıf (ISODATA)	N	Ortalama	Minimum	Maksimum	Std. Sapma
AYS (°C)	Yapılaşmış alan	42793	25.6	18.0	32.7	2.375
	Bitki örtüsü	286479	22.6	18.2	30.3	1.095
	Su yüzeyi	159329	17.3	16.4	31.4	0.806

Kent merkezindeki mahalleleri kapsayan alandaki AYS değerlerinin dağılımı Şekil 4'te gösterilmiştir. Kırmızı alanlar yüksek AYS değerlerini, mavi alanlar ise nispeten düşük AYS değerini göstermektedir. Kent merkezindeki AYS değerleri 18.9 °C ile 32.7 °C arasında değişmektedir. Şekil 4'te AYS değerlerinin mahalleler arasında homojen bir şekilde dağılmadığı açıkça görülmektedir. Örneğin; Güzelyalı ve Kirazlimanı mahallelerinde nispeten düşük AYS değerleri görülürken; Düz, Yeni ve Şarkiye mahalleleri ile Karapınar mahallesinin kuzeyinde çok daha yüksek AYS değerleri gözlenmektedir. Çeşitli mahalleler arasında AYS'deki farklılıkları istatistiksel olarak değerlendirmek için gerçekleştirilen varyans analizinin sonuçları Tablo 6'da ayrıntılı olarak verilmiştir.



Şekil 4. Kent Merkezi ve Mahalleler Ölçeğinde AYS Haritası

1: Akyazı, 2: Aziziye, 3: Bahçelievler, 4: Bucak, 5: Cumhuriyet, 6: Durugöl, 7: Düz, 8: Güzelyalı, 9: Karapınar, 10: Karşıyaka, 11: Kirazlimanı, 12: Kumbaşı, 13: Şahincili, 14: Saray, 15: Şarkiye, 16: Selimiye, 17: Şirinevler, 18: Subaşı, 19: Taşbaşı, 20: Yeni, 21: Zaferimilli

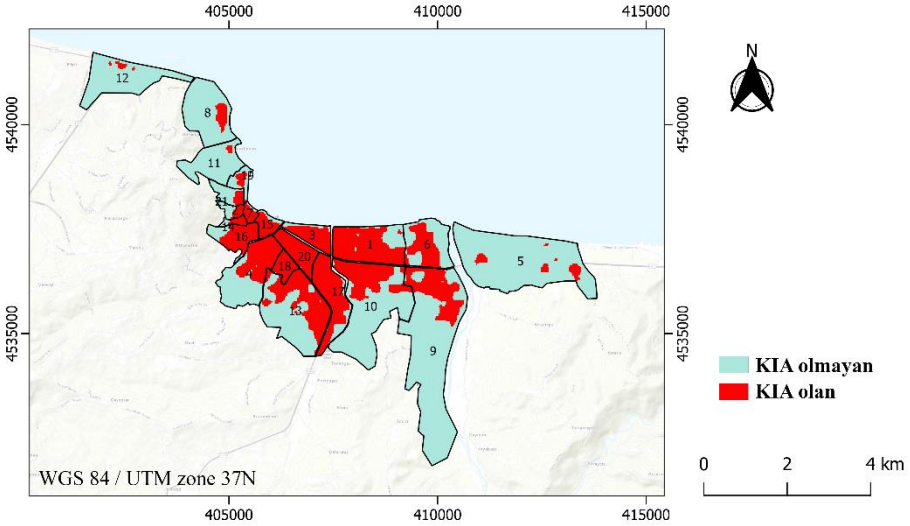
En yüksek AYS ortalamasına sahip mahalleler Yeni (30.6 °C) ve Düz (29.8 °C) olup, ikisi arasında anlamlı bir fark yoktur ($p<0.05$). Bu mahallelerin ortak özellikleri; yapı yoğunluğunun yüksek, yapılar arasındaki mesafenin dar ve yeşil alan miktarının diğer mahallelere göre daha az olmasıdır. En düşük AYS ortalamasına sahip mahalleler ise Güzelyalı ve Kirazlimanı'dır. Her iki mahallede de yapılaşma denize yakın alanlarda veya denize bakan yamaçlarda yoğunlaşmıştır. Bu nedenle, mahalle alanlarının çoğu bitki örtüsü ile kaplıdır. Yoğun bitki örtüsü nedeniyle mahallelerin AYS ortalaması düşmektedir. Ortalama AYS açısından düşük sıralarda yer almasına rağmen en yüksek maksimum AYS'ye sahip mahalle Karapınar'dır (32.7 °C). Bunun nedeni mahalledeki arazi kullanımındaki dengesizliktir. Mahallenin kuzeyinde şehrin en önemli sanayi bölgesi yer almakta olup, en yüksek AYS burada kaydedilmiştir. Ancak mahallenin orta ve güney kesimlerinde neredeyse tamamen kırsal yapı görülmektedir. Sonuç olarak; minimum ve maksimum AYS arasındaki fark burada diğer tüm mahallelere göre daha yüksektir (12.7 °C).

KIA alanlarının ortaya çıkarılması için eşik değeri 27.4 °C olarak hesaplanmıştır. AYS değeri bu eşik değerinin üstünde olan alanlar KIA etkisindeki alanları, eşiğin altında olan alanlar ise KIA etkisinde olmayan alanlardır. Bu alanların mekânsal dağılımı Şekil 5'te sunulmaktadır. Kent merkezinde KIA etkisinde olan ve olmayan alanlar arasında yüzey sıcaklığı bakımından $p<0.05$ düzeyinde anlamlı fark bulunmaktadır (Şekil 6). KIA etkisinin kapsamındaki alanların ortalama yüzey sıcaklığı, KIA etkisinde olmayan alanlardan 4.7 °C daha yüksektir. Kentlerin morfolojik ve topoğrafik yapısı, iklim özellikleri, yapılarda kullanılan malzemeler, açık-yeşil alanların oranı gibi birçok faktör KIA etkisinde olan ve olmayan alanlar arasındaki AYS farkını belirlemektedir (Chen vd., 2021; Kuang vd., 2014; Liu vd., 2021). Örneğin; İtalya'da yürütülen benzer bir çalışmada, KIA etkisindeki alanların ortalama AYS değerinin KIA etkisinde olmayan alanlardan 7.5 °C, Napoli'de ise 12.1 °C daha yüksek olduğu hesaplanmıştır (Guha vd., 2018). Hindistan'ın Raipur kentinde, yaz mevsiminin başında, KIA etkisinde olan ve olmayan bölgeler arasında 2.7 °C'lik bir fark gözlemlenmiştir (Guha vd., 2020).

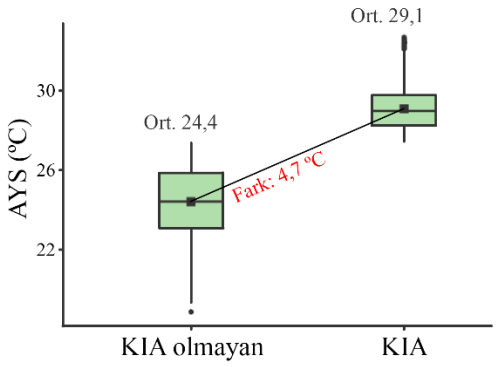
Tablo 6. Kent Merkezindeki Mahalleler Arasındaki AYS Farklılığı

	Mahalle	N (adet)	Ortalama	Minimum	Maksimum	Std. Sapma
AYS (°C)	Yeni	584	30.6*[a]	28.8	31.7	0.67
	Düz	134	29.8[ab]	24.6	32.0	1.86
	Subaşı	288	29.7[b]	27.3	31.5	0.89
	Şarkiye	291	29.5[b]	23.4	32.1	2.18
	Bahçelievler	544	28.9[bc]	23.9	30.9	1.45
	Akyazı	1645	28.6[cd]	24.4	31.3	1.37
	Şirinevler	1216	28.5[cd]	25.5	30.2	0.97
	Selimiye	666	28.2[d]	22.5	31.1	2.28
	Saray	117	27.6[de]	23.2	30.1	1.86
	Şahincili	2587	27.0[e]	22.7	31.0	1.73
	Aziziye	183	26.6[f]	22.4	30.3	2.02
	Bucak	1670	26.6[fg]	21.7	31.6	3.11
	Durugöl	1304	26.6[fg]	20.0	30.1	2.16
	Taşbaşı	268	26.2[fg]	20.9	29.5	1.57
	Karşıyaka	3216	26.1[g]	21.5	31.5	2.39
	Cumhuriyet	4109	25.3[h]	20.1	29.2	1.45
	Karapınar	4976	24.9[i]	20.0	32.7	2.48
	Zaferimilli	321	24.7[i]	21.2	29.4	2.72
	Kumbaşı	1649	24.1[j]	20.2	28.0	1.63
	Güzelyalı	1613	23.3[k]	18.9	29.4	2.51
	Kirazlimanı	1111	23.1[k]	20.2	28.6	1.75

** Küçük harfler Tukey testine göre $p<0.05$ düzeyinde farklı grupları göstermektedir.*

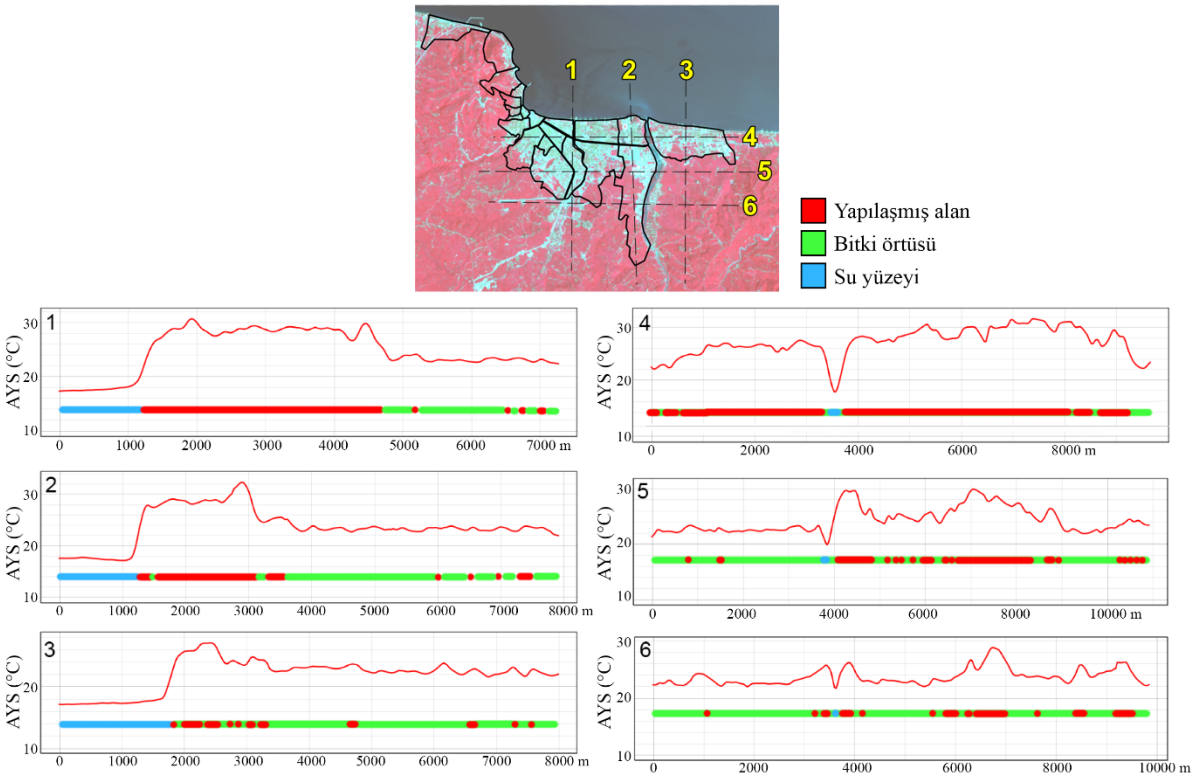


Şekil 5. Kent Merkezi Ölçeğinde KIA Etkisindeki Alanların Mekânsal Dağılımı



Şekil 6. KIA Etkisinde Olan Ve Olmayan Alanlardaki Ortalama AYS Farkı ($p<0.05$)

Kent merkezindeki AYS profilleri ile arazi örtüsü arasındaki ilişki Şekil 7'de gösterilmiştir. AYS değerleri, deniz ve akarsu gibi su kütleleri üzerinde önemli ölçüde azalmaktadır. En yüksek AYS profillerine sahip alanlar yapılaşmış alanları temsil etmektedir. AYS, yapılaşmış alanlar içinde dağılmış bitki örtüsüyle kaplı alanlarda azalma eğilimindedir. AYS'nin yapılaşmış alanlarda çevredeki su yüzeyleri ve bitki örtüsünden daha yüksek olması KIA etkisiyle karakterize edilmektedir. Yapılaşmış alanlardaki AYS dalgalanmalarının nedeninin, yüzey kaplamalarında veya çatılarda kullanılan malzemeler ile binaların yoğunluğu gibi faktörlerle ilgili olabileceği düşünülmektedir.



Şekil 7. Kent Merkezinden Alınan Arazi Örtüsü-AYS Profilleri

Sonuç ve Öneriler

Bu çalışmada, KIA etkisi ile arazi örtüsü arasındaki ilişkiyi belirlemek için uzaktan algılama verilerine dayalı bir araştırma yürütülmüştür. Üç temel arazi örtüsü sınıfı için denetimsiz sınıflandırma yapılmıştır: yapılaşmış alanlar, bitki örtüsü ile kaplı alanlar ve su yüzeyleri. Sonuç olarak; yapılaşmış alanlardaki AYS ortalamasının çevredeki yapılaşmamış alanlardan önemli ölçüde daha yüksek olduğu bulunmuştur. Bu nedenle, Ordu kent merkezinde "kentsel ısı adası" etkisinden bahsedilebilmektedir. Bununla birlikte, söz konusu ısı adalarının dağılımı homojen değildir. Kent merkezinde, henüz tamamen yapılaşmamış bazı mahalleler nispeten daha avantajlı durumdadır. Yakın gelecekte bu mahallelerde ısı adalarının oluşmasını önlemek için iklim tabanlı bir arazi kullanım planlaması yapılmalıdır.

Dünya çapında birçok araştırmacı; kentlerde fiziksel, sosyal ve sağlıkla ilgili problemlere neden olan KIA etkisini azaltmak için çalışmalar yürütmektedir (Akbari vd., 2015; Cao vd., 2023; Ren vd., 2013; Wang, 2019; Yang vd., 2022;). Bu kapsam ülkeler ölçeğinde genişletildiğinde, iklim değişikliği olgusunun zararlarından korunmak ve iklim değişikliğiyle mücadele etmek için önemli adımlar atıldığı görülmektedir. Kentlerde KIA etkisini azaltmak için bölgesel ve yerel ölçeklerde envanter ve haritalama çalışmaları yapılmalıdır. Bu çalışma, Ordu kenti ve yakın çevresi için KIA etkisini haritalama ve arazi örtüsüyle ilişkilendirme konusundaki ilk adımlardan biridir. Bu açıdan, gelecekte kentte ve Karadeniz Bölgesi'nde yapılacak diğer çalışmalar için önemli bir referans olacaktır.

Oluşturduğumuz AYS haritasında, yüksek AYS değerlerinin kent merkezinde yoğunlaştığını gözlemledik. Ordu kent merkezinde, yeşil örtü çevredeki kırsal alanlara kıyasla genellikle sınırlıdır ve geçirimsiz yüzeyler yaygındır. Buna ek olarak; motorlu taşıtlar, sanayi alanları ve konutlar gibi antropojenik ısı kaynakları da kent merkezinde yer almaktadır. Küresel iklim değişikliğiyle birlikte artan ortalama sıcaklıklar devreye girdiğinde, özellikle yaz aylarında KIA etkisi hissedilmekte ve termal konfor seviyesi önemli ölçüde düşmektedir. Çalışmanın sonuçları; arazi örtüsü tipi ile KIA oluşumu arasındaki bağlantıyı doğrulamıştır. Üç temel arazi sınıfı arasında en yüksek AYS ortalaması, yapılaşmış alanlarda gözlenmiştir. Ordu kenti, nüfus artışı nedeniyle özellikle güney ve doğu yönlerinde kentsel genişleme

sürecindedir. Bu kentleşme süreci, bitki örtüsünün yapılaşmış alanlara dönüşmesine neden olmakta ve geçirimsiz yüzeylerin oranını artırmaktadır. Bu nedenle yerel ölçekte alınması gereken ilk önlem, kentsel genişlemenin kontrol altına alınmasıdır. Kentsel morfoloji, kentlerde KIA oluşumunu ve KIA etkisindeki alanların dağılımını önemli ölçüde etkilemektedir (Huang ve Wang, 2019; Liu vd., 2020; Touchaei ve Wang, 2015; Zhou ve Hong, 2018). Yapılaşma yönündeki kontrolsüz arazi değişiklikleri, KIA etkisindeki alanların genişlemesine neden olabilir.

Kentsel yeşil alanların, şehirlerdeki yaşam kalitesini artırdığı ve kentsel yaşana bilirliği geliştirdiği yaygın olarak kabul edilmektedir (Grilo vd., 2020). Kentsel yeşil alanlar ve ağaçlar, kentlerde KIA etkisini azaltmada da önemli bir rol oynamaktadır. Sri Lanka'da yapılan bir çalışma, bitki örtüsünün KIA etkisini düzenlediğini ortaya koymuştur (Galagoda vd., 2018). Bu nedenlerden dolayı, kentteki yeşil altyapı sistemine odaklanan bir planlama yaklaşımı benimsenmelidir. Mevcut kentsel açıklıklar ve yol kenarları bitkilendirilmeli, kentteki bitki örtüsü oranı iyileştirilmelidir. Kentsel yeşil alanların sayısını artırmak, KIA etkisini azaltmak için yeterli olmayabilir (Azevedo vd., 2016; Bao vd., 2016). Yeşil alanların KIA etkisini azaltmadaki performansı, yeşil alanların büyüklüğü ve dağılımı, şehir planlaması ve kullanılan kentsel malzemelerin türü ve yerel meteorolojik koşullar gibi çeşitli faktörlere bağlıdır (Huang vd., 2018; Icaza ve Hoeven, 2017). Yeşil çatılar da KIA etkisini azaltma stratejilerinde önemli bir yere sahiptir (Akbari vd., 2015; Li vd., 2014; Mittermüller vd., 2021; Tan vd., 2009). Bu nedenlerden dolayı, kentsel ölçekte yeşil çatıların yaygın kullanımı KIA etkisininin yaratabileceği olumsuz durumları ortadan kaldırmaya yardımcı olabilir. Ayrıca, iklim faktörünü önceleyen kentsel yenileme çalışmalarının genel olarak mikroklimatik koşulları iyileştirdiğine dair önemli araştırmalar bulunmaktadır (Yucekaya ve Tirnakci, 2023).

Çalışmaya sınırlı sayıda arazi örtüsü sınıfı dahil edilmiştir. Ancak gelecekteki araştırmalarda, daha fazla arazi örtüsü sınıfı ya da "Yerel İklim Bölgeleri" gibi iklim çalışmaları için geliştirilen etkili sınıflandırma yöntemleri kullanılabilir. Ayrıca, bu çalışmada, AYS tahmini tamamen uzaktan algılama verileri kullanılarak yapılmıştır. Hesaplanan AYS değerinin doğruluğunu değerlendirmek için çalışma sonuçlarının yersel ölçümlerle desteklenmesi önemlidir.

Kent çevresindeki kentsel yeşil alanlar ve doğal/yapay bitki örtüsü alanları, kentleri ve kentlerde yaşayan sakinleri iklim değişikliğinin olası olumsuz etkilerinden korumada önemli bir yere sahiptir. İklim değişikliği mikro, makro ve küresel ölçekte kaçınılmaz bir olgudur. Bu nedenle kentsel ölçekte risk bölgelerini belirlemek ve gerekli önlemleri almak elzemdir. Bilhassa kentin yeni gelişim gösterdiği alanlarda ısı adalarının oluşumunu önlemek veya etkilerini hafifletmek için etkili bir arazi kullanım planlaması yapılmalıdır. İklim değişikliğine uyum politikalarının etkili bir şekilde formüle edilmesiyle olası olumsuz etkilere karşı daha dirençli kentler yaratılabilecektir.

Yazar Katkısı

Yazarlar makaleyi birlikte yazdı, okudu ve onayladı.

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Bu makalenin yayınlanmasıyla ilgili herhangi bir etik sorun bulunmamaktadır.

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Yazarlar herhangi bir çıkar çatışması olmadığını belirtmektedir.

ORCID

Mesut Güzel https://orcid.org/0000-0001-6172-5812

Pervin Yeşil https://orcid.org/0000-0003-4395-6881

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Simplicial Lie-Rinehart Algebras with Related Structures

Ali Aytekin[1], Mahmut Koçak[2]

[1] Pamukkale University, Faculty of Science, Department of Mathematics, Denizli
[2] Eshişehir Osmangazi University, Faculty of Science, Department of Mathematics and Computer, Eskişehir

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Abstract

In this paper, simplicial Lie-Rinehart algebras and Lie-Rinehart cat^1-algebras will be defined. With the help of these definitions, the relations between Lie-Rinehart crossed modules, cat^1 -algebras and simplicial Lie-Rinehart algebras will be explained.

Anahtar Kelimeler: Lie-Rinehart algebra, simplicial object, crossed module

İlgili Yapılarla Simplisel Lie-Rinehart Cebirler

Öz

Bu çalışmada, simplisel Lie-Rinehart cebirler ve Lie-Rinehart cat^1 -cebirler tanımlanacaktır. Bu tanımlamalar yardımıyla, Lie-Rinehart çaprazlanmış modüller, cat^1-cebirler ve simplisel Lie-Rinehart cebirler arasındaki ilişki açıklanacaktır.

Keywords: Lie-Rinehart cebir, simplisel obje, çaprazlanmış modül

Sorumlu Yazar / Corresponding Author: Ali Aytekin aaytekin@pau.edu.tr

Introduction

Lie-Rinehart algebras represent a significant structure that examines the interactions between Lie algebras and differential geometry. These structures are defined as general constructions related to both Lie algebras and modules over commutative algebras and offer a rich and profound field of research in topics related to differential algebraic structures. Particularly, the study of modules over Lie-Rinehart algebras is crucial for understanding the geometric and algebraic properties of these structures. In this context, the crossed modules of Lie-Rinehart algebras emerge as a generalization of similar concepts in differential geometry and homological algebra. These were firstly introduced by Herz in (Herz, 1953). Lie-Rinehart algebras have a very close relationship to Lie algebroids and are their section spaces. For more information, see (Huebschmann, 1990; Mackenzie, 1987).

Lie-Rinehart crossed modules represent a significant concept that merges algebraic and differential structures. These modules enable the formulation of a Lie algebra as a module while exploring the interactions of these structures across different mathematical contexts. These structures are critically important, particularly in the representation theory of Lie algebras and the study of geometric structures. The applications of these modules are extensive in fields such as differential geometry, algebraic geometry, and theoretical physics. For instance, Lie-Rinehart modules enable a better understanding of the relationships between differential forms and vector fields, thus providing a foundation for a deeper exploration of symmetries and structures. In conclusion, Lie-Rinehart crossed modules reveal connections between mathematical theories and structures, making significant contributions to both theoretical and applied research. In this context, a thorough investigation of these modules can offer new perspectives in various disciplines of modern mathematics. On the other hand, crossed modules for Lie-Rinehart algebras were defined in (Casas et al., 2004) to provide extensive information about the cohomology of Lie-Rinehart algebras. Afterwards, the authors have contributed the subject with the studied (Casas, 2011; Casas et al., 2005).

Our main purpose in this article is to define simplicial Lie-Rinehart algebras and Lie-Rinehart cat^1-algebras, and give natural equivalences between the category of Lie Rinehart crossed modules, Lie Rinehart cat^1-algebras and one dimensional simplicial Lie-Rinehart algebras. In addition, fort he Lie algebra and categorical aspect with see (Arvasi & Akça, 2002).

Preliminaries

In this section, the fundamental concepts and properties that will be used in the article will be given. For the detailed information about the definitions and theorems that we restate see (Casas et al., 2004; Herz, 1953). Throughout this article, r will be taken as a field, C as a commutative algebra over r, and $Der(C)$ as the set of r-derivations of C.

Definition 1. *Let $\mathcal{X}$ be a Lie r-algebra and an C-module and $\gamma: \mathcal{X} \to Der(C)$ is an C-module and a Lie r-algebra homomorphism. So, $(\mathcal{X},\gamma)$ is called a Lie-Rinehart C-algebra over C (or shortly called L-R algebra) and denoted by $\mathcal{X}$, if*

$$[x, cx'] = c[x, x'] + x(c)x'$$

for all $x, x' \in \mathcal{X}$, $c \in C$ where $x(c) = \gamma(x)(c)$.

Definition 2. *Let $\mathcal{X}$ and $\mathcal{X}'$ be L-R algebras. Let $\zeta: \mathcal{X} \to \mathcal{X}'$ be a Lie algebra homomorphism and an C-module homomorphism. If the diagram*

$$\begin{tikzcd} \mathcal{X} \arrow[dr, "\gamma"] \arrow[dd, "\zeta"'] & \\ & Der(C) \\ \mathcal{X}' \arrow[ur, "\gamma'"'] & \end{tikzcd}$$

is commutative then ζ is called a L-R algebra homomorphism.

So, we have the category of L-R algebras and we denote this category by $\mathfrak{LR}(C)$.

Example 3. *If $\gamma = 0$ for a Lie-Rinehart algebra $\mathcal{X}$ then $\mathcal{X}$ is a Lie C-algebra. Also, $Der(C)$ is a L-R algebra.*

Example 4. *If $\mathcal{X}$ is a L-R algebra, then $\mathcal{X} \rtimes C$ with Lie bracket*

$$[(x,c),(x',c')] = \big([x,x'], x(c') - x'(c)\big)$$

and map

$$\tilde{\gamma}: \mathcal{X} \rtimes C \to Der(C),\ \tilde{\gamma}(x,\mathrm{c}) = \gamma(x)$$

is a L-R algebra, where γ is $\gamma: \mathcal{X} \to Der(C)$.

Definition 5. *Let $\mathcal{X}$ be a L-R algebra . A L-R subalgebra $\mathcal{N}$ of $\mathcal{X}$ consists of a Lie r-subalgebra $\mathcal{N}$ which is an C-module and C acts on $\mathcal{N}$ via the composition*

$$\mathcal{N} \hookrightarrow \mathcal{X} \xrightarrow{\gamma} Der(C).$$

It is trivial that a L-R subalgebra $\mathcal{N}$ of $\mathcal{X}$ is an ideal if $\mathcal{N}$ is an ideal of $\mathcal{X}$ as Lie r -algebra with the following composition

$$\mathcal{N} \hookrightarrow \mathcal{X} \xrightarrow{\gamma} Der(C).$$

Definition 6. *Let $\mathcal{X}$ be a L-R algebra and Y be a Lie C -algebra. The action of $\mathcal{X}$ on Y is a r -linear map*

$$\begin{array}{ccc} \mathcal{X} \times Y & \to & Y \\ (x,y) & \mapsto & {}^{x}y \end{array}$$

satisfies the following axioms

1. ${}^{[x,x']}y = {}^{x}\left({}^{x'}y\right) - {}^{x'}({}^{x}y)$
2. ${}^{x}[y_1,y_2] = [{}^{x}y_1, y_2] + [y_1, {}^{x}y_2]$
3. ${}^{cx}y = c({}^{x}y)$
4. ${}^{x}(cy) = c({}^{x}y) + \big(\zeta(x)(c)\big)y,$

for all $x, x' \in \mathcal{X}$, $y, y_1, y_2 \in Y$ and $c \in C$.

Definition 7. *Let $\mathcal{X}$ be a L-R algebra, Y be a Lie C -algebra and $\mathcal{X}$ acts on Y. Then $\mathcal{X} \rtimes Y$ is a Lie r-algebra with the Lie bracket*

$$[(x,y),(x',y')] = \big([x,x'], [y,y'] + {}^{x}y' - {}^{x'}y\big).$$

This construction is called semi-direct product of $\mathcal{X}$ and Y. If we define

$$\tilde{\gamma}: \mathcal{X} \rtimes Y \to Der(C),\ \tilde{\gamma}(x,y) = \gamma(x)$$

then the pair $(\mathcal{X} \rtimes Y, \tilde{\gamma})$ is a L-R algebra.

Definition 8. *Let Y be an abelian Lie C-algebra and $\mathcal{X}$ be a L-R C-algebra. If $\mathcal{X}$ acts on Y then we call Y as a L-R module over $\mathcal{X}$ or shortly $(\mathcal{X}, C)$-module .*

Crossed Modules

Crossed modules are a fundamental concept in algebraic topology and homological algebra, providing a way to study the interplay between group theory and homotopy theory. Put forward by Whitehead in (Whitehead, 1949), crossed modules generalize the notion of groups and their actions, allowing for a more nuanced understanding of how different algebraic structures can interact. This setup allows us to capture the idea of a group acting on another group, where the action is governed by the homomorphism. One of the key motivations for studying crossed modules is their role in the classification of 2-categories and the study of higher-dimensional algebra. They provide a framework for understanding how groups can be built up from simpler components, similar to how topological spaces can be constructed from simplices. Following Whitehead's definition, many researchers have investigated the properties of crossed modules by defining them on various algebraic structures (Aytekin & Şahan, 2022; Gürmen, 2023; Odabaş et al., 2016; Şahan, 2019).

Now, we will recall the definition of the Lie-Rinehart crossed module (or shortly called L-R crossed module). The examples, remarks and propositions for L-R crossed modules similar to crossed modules of commutative algebras and Lie algebras given in many different papers in the references. But many parts of the proofs are different for L-R algebra case.

Definition 9. *Let $\mathcal{X}$ be a L-R algebra, Y be a Lie C -algebra and $\mathcal{X}$ acts on Y. Lie r-algebra homomorphism $\partial: Y \to \mathcal{X}$ is called L-R crossed module such that the following identities hold*

1. $\partial({}^{l}y) = \left({}^{l}\partial(y)\right)$
2. $[\partial(y'), y] = [y', y]$
3. $\partial(cy) = c\,\partial(y)$
4. $\partial(y)(c) = 0,$

for all $y, y' \in Y$, $x \in \mathcal{X}$ and $c \in C$. This structure is denoted by $(Y, \mathcal{X}, \partial)$.

As indicated in (Casas et al., 2004), the third condition says that ∂ is an C-module homomorphism and the fourth condition says that the composition

$$Y \xrightarrow{\partial} \mathcal{X} \xrightarrow{\gamma} Der(C)$$

is zero.

Example 10. *Let $\mathcal{X}$ be a L-R algebra and I is an ideal of $\mathcal{X}$. With homomorphim*

$$\begin{array}{rcl} i: I & \to & \mathcal{L} \\ l & \mapsto & l \end{array}$$

and action

$$\begin{array}{rcl} \mathcal{X} \times I & \to & I \\ (x,t) & \mapsto & [x,t] \end{array}$$

for all $t \in \mathrm{I}, x \in \mathcal{X}$, $(I, \mathcal{X}, i)$, *is a L-R crossed module.*

Example 11. *Let* Y *be a* $(\mathcal{X}, C)$*-module. Then* $0: Y \to \mathcal{X}$ *is a L-R crossed module.*

Example 12. *Let* $\beta: Y \to Y'$ *be a homomorphism of* $(\mathcal{X}, C)$*-modules. We define an action of* $\mathcal{X} \rtimes Y'$ *on* Y *with* $(x, y') \cdot y = xy$ *for all* $x \in \mathcal{X}$, $y \in Y$ *and* $y' \in Y'$. *Define*

$$\begin{array}{rcl} \partial: Y & \to & \mathcal{X} \rtimes Y' \\ y & \mapsto & (0, \beta(y)), \end{array}$$

then $(Y, \mathcal{X} \rtimes Y', \partial)$ *is a L-R crossed module.*

Definition 13. *Let* $(Y, \mathcal{X}, \partial)$ *and* $(Y', \mathcal{X}', \partial')$ *be L-R crossed modules. The homomorphism between these two crossed modules is the pair* (f, ϕ) *of Lie* r*-algebra homomorphism* $f: Y \to Y'$ *and L-R algebra homomorphism* $\phi: \mathcal{X} \to \mathcal{X}'$ *such that*

$$f(x \cdot y) = \phi(x) \cdot f(y),\ \partial' f(y) = \phi\, \partial(y).$$

Thus, the category of L-R crossed modules whose objects are L-R crossed modules and whose morphisms are homomorphism pairs is defined and this category is denoted as $\mathfrak{Xmod}(\mathfrak{LR})$.

Now, we will give some basic functorial properties of this category. Obviously, we can easily define some forgetful functors as follows;

$$\begin{array}{rcl} U_1: \mathfrak{Xmod}(\mathfrak{LR}) & \to & \mathfrak{LR}(C) \\ (Y, \mathcal{X}, \partial) & \mapsto & \mathcal{X} \end{array}$$

$$\begin{array}{rcl} U_2: \mathfrak{Xmod}(\mathfrak{LR}) & \to & \mathfrak{L}(C) \\ (Y, \mathcal{X}, \partial) & \mapsto & Y \end{array}$$

where $\mathfrak{L}(C)$ represents the category of Lie algebras. Also, if we denote the category of Lie r-algebras by $\mathfrak{Xmod}(\mathfrak{Lie})$ then we have

$$U_3: \mathfrak{Xmod}(\mathfrak{LR}) \to \mathfrak{Xmod}(\mathfrak{Lie})$$

which forgets the C-module structure.

Simplicial L-R Algebras

Simplicial algebras are a branch of mathematics that arises from the interplay between algebraic structures and topological concepts, particularly in the study of simplicial sets and simplicial complexes. At its core, simplicial algebra provides a framework for understanding how algebraic operations can be performed on geometric objects, enabling mathematicians to explore relationships between topology, homotopy theory, and category theory. The fundamental building blocks of simplicial algebras are simplices geometric objects such as points, line segments, triangles, and higher-dimensional analogs. These simplices are organized into higher-dimensional structures known as simplicial complexes, which serve as a way to study spaces through combinatorial and algebraic methods. One of the key contributions of simplicial algebra is its ability to capture homotopical properties of topological spaces through algebraic invariants, such as homology and cohomology groups. This provides for a wide understanding of the shape and connectivity of spaces, bridging the gap between algebraic and geometric perspectives.

Now, we recall the definition of simplicial object in (Goerss & Jardine, 2009). Let $\mathfrak{C}$ be a category with all finite colimits and consider $s\mathfrak{C}$, the category of simplicial objects in $\mathfrak{C}$. A simplicial object in $\mathfrak{C}$ is

defined as a contravariant functor $\Delta^{op} \to \mathfrak{C}$ from the ordinal number category Δ. In this context, a simplicial L-R algebra (or shortly called SL-R algebra) $\mathbf{X}$ is a sequence of L-R algebras

$$\mathbf{X} = \{X_0, X_1, \dots, X_n, \dots\}$$

together with face and degeneracy maps

$$\begin{array}{lll} d_i^n: & X_n & \to X_{n-1} \\ s_i^n: & X_n & \to X_{n+1} \end{array}$$

for all $0 \leq i \leq n, n \neq 0$ which are L-R homomorphisms satisfying the general simplicial identities.

The Moore Complex

The Moore complex $\mathbf{NX}$ of a simplicial L-R algebra $\mathbf{X}$ is the complex

$$\mathbf{NX}: \dots \mathrm{N}X_n \overset{\partial_n}{\to} \mathrm{N}X_{n-1} \overset{\partial_{n-1}}{\to} \dots \overset{\partial_2}{\to} \mathrm{N}X_1 \overset{\partial_1}{\to} \mathrm{N}X_0$$

where $NX_0 = X_0, NX_n = \bigcap_{i=0}^{n-1} Kerd_i$ and ∂_n is the restriction of d_n to NX_n.

We express that the Moore complex $\mathbf{NX}$ of a SL-R algebra $\mathcal{X}$ is of length k if $NX_n = 0$ for all $n \geq k+1$. In this situation since the kernel of a L-R homomorphism is a Lie C-algebra, so NX_n is a Lie C-algebra for $n \geq 1$. So, it can be defined the category of SL-R denoted by $\mathfrak{Smp}_{\leq n}(\mathfrak{LR})$ whose objects are SL-R algebras with Moore complex of length n and the morphisms are families of L-R homomorphisms suitable with face and degeneracy maps.

Truncated SL-R Algebras

Details of the group case can be found in (Curtis, 1971). For each $k \geq 0$ we have a subcategory of Δ, denoted as $\Delta_{\leq k}$ obtained by the objects $[j]$ of Δ with $j \leq k$. A truncated SL-R algebra is $\Delta_{\leq k}^{op} \to \mathfrak{LR}(C)$. As a consequence a truncated SL-R algebra is a family of L-R algebras $\{X_0, X_1, \dots, X_k\}$ and homomorphism $d_i: X_n \to X_{n-1}$, $s_i: X_n \to X_{n+1}$ for each $0 \leq i \leq n$ which previously mentioned. We denote the category of k -truncated SL-R algebras by $\mathfrak{Tr}_k\mathfrak{Smp}(\mathfrak{LR})$. Also, there is the functor $tr_k: \mathfrak{Smp}(\mathfrak{LR}) \to \mathfrak{Tr}_k\mathfrak{Smp}(\mathfrak{LR})$ and the following relationship exists between it and the st_k and $cost_k$ functors;

$$\mathfrak{Tr}_k\mathfrak{Smp}(\mathfrak{LR}) \underset{cost_k}{\overset{tr_k}{\leftrightarrows}} \mathfrak{Smp}(\mathfrak{LR}) \underset{st_k}{\overset{tr_k}{\rightleftarrows}} \mathfrak{Tr}_k\mathfrak{Smp}(\mathfrak{LR}).$$

For the definitions of the functors $cost_k$ and st_k see (Curtis, 1971).

Theorem 14. *The category $\mathfrak{Xmod}(\mathfrak{LR})$ is naturally equivalent to the category $\mathfrak{Smp}_{\leq 1}(\mathfrak{LR})$.*

Proof. Let X be an object of $\mathfrak{Smp}_{\leq 1}(\mathfrak{LR})$. Take $Y = \mathrm{ker} d_0$ (so Y is a Lie C -algebra) and ∂ is the restriction of d_1 to Y. Action of X on Y is defined as

$$\begin{array}{ccc} X_0 \times Y & \to & Y \\ (x, y) & \mapsto & {}^{x}y = [s_0 x, y] \end{array}$$

for $x \in X$ and $y \in Y$. It is easy to check the conditions of the action.

Since the maps

$$X_1 \underset{s_0}{\overset{d_0, d_1}{\rightrightarrows}} X_0$$

are L-R algebra homomorphism, we have the following commutative diagrams

$$\begin{tikzcd} X_1 \arrow[rr, "d_0"] \arrow[dr, "\gamma'"'] & & X_0 \arrow[dl, "\gamma"] \\ & Der(C) \arrow[u, phantom, "\gamma d_0 = \gamma'"] & \end{tikzcd} \quad \begin{tikzcd} X_1 \arrow[rr, "d_1"] \arrow[dr, "\gamma'"'] & & X_0 \arrow[dl, "\gamma"] \\ & Der(C) \arrow[u, phantom, "\gamma d_1 = \gamma'"] & \end{tikzcd}$$

$$\begin{tikzcd} X_1 \arrow[dr, "\gamma'"'] & & X_0 \arrow[ll, "s_0"'] \arrow[dl, "\gamma"] \\ & Der(C) \arrow[u, phantom, "\gamma' s_0 = \gamma"] & \end{tikzcd}$$

By using the commutativity of diagrams and some simplicial identities we have

CM 1:

$$\begin{aligned} \partial({}^{x}y) &= \partial[s_0 x, y] \\ &= [d_1 s_0 x, d_1 y] \\ &= [x, \partial y] \qquad (\because\ d_1 s_0 = id). \end{aligned}$$

CM 2: Employing similar manner we provide the following identity

$$\partial({}^{y'})y \quad = \quad [y', y].$$

CM 3:

$\partial(cy) = c\,\partial(y)$ (since ∂, is a C -module homomorphism)

CM 4: Taking advantgre of the definitions and properties, we obtain the following

$$\partial(y)(c) \quad = \quad 0.$$

The homomorphism $\partial: Y \to X$ is a L-R crossed module . So we obtain a functor

$$N_1: \mathfrak{Smp}_{\leq 1}(\mathfrak{LR}) \to \mathfrak{Xmod}(\mathfrak{LR})$$

Conversely let $\partial: Y \to X$ be a L-R crossed module. With the action of X on Y we can create

$$X_1 = X \rtimes Y = \{(x, y): x \in X, y \in Y\}.$$

For all $c \in C, x, x' \in X_0$ and $y, y' \in Y$ the scalar multiplication, sum and multiplication defined as

$$\begin{aligned} c(x, y) &= (cx, cy), \\ (x, y) + (x', y') &= (x + x', y + y'), \\ [(x, y), (x', y')] &= \left([x, x'], [y, y'] + {}^{x}y' - {}^{x'}y\right), \end{aligned}$$

respectively. We have the homomorphisms

$$\begin{aligned} d_0: \quad & X \rtimes Y \to X \\ & (x, y) \mapsto x \\ d_1: \quad & X \rtimes Y \to X \\ & (x, y) \mapsto (\partial y) + x \\ s_0: \quad & X \to X \rtimes Y \\ & x \mapsto (x, 0) \end{aligned}$$

and these maps satisfy the simplicial identities.

Now we must show that these maps are L-R homomorphisms. Since

$$\gamma d_0 = \tilde{\gamma}, \gamma d_1 = \tilde{\gamma} \text{ and } \tilde{\gamma} s_0 = \gamma$$

we have

$$\gamma d_0 = \tilde{\gamma} = \gamma, \gamma d_1 = \tilde{\gamma} = \gamma \text{ and } \tilde{\gamma} s_0 = \gamma s_0 = \gamma$$

so the maps are L-R homomorphisms (other conditions are omitted as they easy to check). Finally

$$\begin{tikzcd} X_1 \arrow[r, shift left=2] \arrow[r, shift left] \arrow[r, shift right] & X_0 \arrow[l, shift left] \end{tikzcd}$$

is an object of $\mathfrak{Tr}_1\mathfrak{Smp}(\mathfrak{LR})$. So, we have

$$M: \mathfrak{Xmod}(\mathfrak{LR}) \to \mathfrak{Tr}_1\mathfrak{Smp}(\mathfrak{LR}).$$

On the other hand we have the functor

$$st_1: \mathfrak{Tr}_1\mathfrak{Smp}(\mathfrak{LR}) \to \mathfrak{Smp}_{\leq 1}(\mathfrak{LR}).$$

Thus, with the combination of the st_1 and M functors we obtain

$$N_2: \mathfrak{Xmod}(\mathfrak{LR}) \to \mathfrak{Smp}_{\leq 1}(\mathfrak{LR}).$$

So, thanks to the functors N_1 and N_2, the natural equivalence between the two categories is shown.

Cat^1 L-R Algebras

Cat^1 algebras emerge from the intersection of category theory and algebra, offering a powerful framework for studying algebraic structures through categorical concepts. By viewing algebraic entities such as groups, rings, and modules as objects within a category, Cat^1 algebras enable a deeper exploration of their relationships and transformations. In this context, a Cat^1 algebra can be understood as a category with a single object, where morphisms correspond to the algebraic operations defined on that object. This perspective allows for the analysis of algebraic properties in a more general setting, facilitating the investigation of homomorphisms, automorphisms, and extensions in a unified manner. One of the main advantages of Cat^1 algebras is their ability to capture the essence of algebraic structures while retaining the flexibility of categorical operations. This approach not only enhances the understanding of traditional algebraic concepts but also bridges connections to other areas of mathematics, such as topology and homological algebra.

Cat^1 groups were defined by Loday in (Loday, 1982). He developed this concept to explore the connections between categorical structures and group theory. Cat^1 groups provide an important framework for understanding how groups are structured within a category and how relationships between groups can be studied. Following Loday's definition, many researchers have investigated the properties of this structure on various algebraic structures (Alp, 1998; Alp & Gürmen, 2003; Arvasi & Odabaş, 2016; Şahan & Kendir, 2023, Temel,2019).

Definition 15. *A cat^1 L-R algebra is a triple $(\mathcal{X}, s, t)$ where $\mathcal{X}$ is a L-R algebra, s and t are L-R homomorphisms such that;*

$i)$ $st = t$ and $ts = s$

$ii)$ $[\ker s, \ker t] = 0.$

Obviously we can form the category of cat^1 L-R algebras where the morphisms are L-R algebra homomorphisms suitable with the source and target maps. We will denote this category by $\mathfrak{Cat}^1(\mathfrak{LR})$.

We refer (Arvasi, 1997) for commutative algebra case of below proposition.

Proposition 16. *The category* $\mathfrak{Xmod}(\mathfrak{LR})$ *is naturally equivalent to the category* $\mathfrak{Cat}^1(\mathfrak{LR})$.

Proof. Let $(\mathcal{X}, s, t)$ be a cat^1 L-R algebra, $M = \ker s, \mathrm{N} = \mathrm{Im}s$ and $\partial = t|_M$. First of all we have $\gamma s = \gamma$ and $\gamma t = \gamma$, so $\gamma s = \gamma t$. Define the action of N on M by ${}^n m = [n, m]$. Since M is a kernel L-R homomorphism so is a Lie A-algebra. The first two conditions are trivial as indicated in for commutative algebra case. In the fourth condition we must use the fact that $\alpha s = \alpha t$ which is different from the commutative algebra case.

CM 4: Since s and t are L-R algebra homomorphisms, $\gamma s = \gamma t = \gamma$. So for $m \in M$ and $c \in C$ we have

$$\begin{aligned}
\partial(m)(c) &= \big(\gamma(\partial m)\big)(c) \\
&= \big(\gamma(tm)\big)(c) \\
&= \big(\gamma(sm)\big)(c) \quad (\gamma t = s = \gamma s) \\
&= \big(\gamma(0)\big)(c) \quad (\text{ Since } m \in \ker s = M) \\
&= 0
\end{aligned}$$

From above calculations $\partial: M \to N$ is a L-R crossed module.

Conversely, given a crossed module for L-R algebra $(\mathcal{X}, Y, \partial)$. $Y \ltimes \mathcal{X}$ is a L-R algebra as proved in (Casas et al., 2004).

Define s, t as;

$$\begin{array}{rccc}
s: & Y \ltimes \mathcal{X} & \to & Y \ltimes \mathcal{X} \\
 & (y, x) & \mapsto & (0, x)
\end{array}$$

and

$$\begin{array}{rccc}
t: & Y \ltimes \mathcal{X} & \to & Y \ltimes \mathcal{X} \\
 & (y, x) & \mapsto & (0, \partial y + x)
\end{array}$$

It is easy to check that s and t are C-module and Lie r-algebra homomorphisms. Here we will show the commutativity of the diagrams

$$\begin{tikzcd}
Y \ltimes \mathcal{X} \arrow[rr, shift left, "s"] \arrow[rr, shift right, "t"'] \arrow[dr, "\tilde{\gamma}"'] & & Y \ltimes \mathcal{X} \arrow[dl, "\tilde{\gamma}"] \\
& Der(C) &
\end{tikzcd}$$

Since

$$\begin{aligned}
\big(\tilde{\gamma}(s)\big)(y, x) &= \tilde{\gamma}(0, x) \\
&= \gamma(x) \\
&= \tilde{\gamma}(y, x),
\end{aligned}$$

$$\begin{aligned}
\big(\tilde{\gamma}(t)\big)(y, x) &= \tilde{\gamma}(0, \partial y + x) \\
&= \gamma(\partial y + x) \\
&= \gamma\, \partial y + \gamma x \\
&= 0 + \alpha x \\
&= \tilde{\gamma}(y, x),
\end{aligned}$$

we have that s and t are L-R homomorphisms. Also $st = t$ and $ts = s$, that is,

$$\begin{aligned} s\big(t(y,x)\big) &= s(0,\partial y + x) \\ &= (0,\partial y + x) \\ &= t(y,x) \end{aligned}$$

and

$$\begin{aligned} t\big(s(y,x)\big) &= t(0,x) \\ &= (0,x) \\ &= s(y,x). \end{aligned}$$

So, we have $\ker s = \{(y,0) \mid y \in Y\}$ and $\ker t = \{(y,-\partial y) \mid y \in Y\}$. We have $[\ker s, \ker t] = 0$, since

$$\begin{aligned} [(y,0),(y',-\partial(y'))] &= \big([y,y']-^{-\partial y'}y+^{0}y',[0,-\partial y']\big) \\ &= \big([y,y']+^{\partial y'}y+0,0\big) \\ &= ([y,y']+[y',y],0) \\ &= (0,0). \end{aligned}$$

Conclusion and Suggestions

In this study, simplicial Lie-Rinehart algebras and Lie-Rinehart cat^1-algebras are defined. Also, the relationships between Lie-Rinehart crossed module, cat^1-algebra and simplicial Lie-Rinehart algebra categories are mentioned. Similar studies can be done using crossed modules on different algebraic structures.

Author Contribution

The authors co-wrote, read and approved the manuscript.

Ethics

There are no ethical issues regarding the publication of this article.

Conflict of Interest

The authors declare that they have no conflict of interest.

ORCID

Ali Aytekin https://orcid.org/0000-0001-7892-6960

Mahmut Koçak https://orcid.org/0000-0001-7774-0144

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Determination of Compatible Plasticizer to Calcined Marl Blended Cement

Yasemin Akgün[1], Murat Usta[2]

[1] Ordu University, Technical Sciences Vocational School, Department of Construction Technologies, Ordu
[2] Ordu University, Institute of Science, Renewable Energy Department, Ordu

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Abstract

Compatibility research between calcined marl (CM) blended cement and three plasticizers with different origins such as naphthalene sulphonate–formaldehyde (NSF), vinyl copolymer (VCP) and polycarboxylate ether (PCE) were performed. The effects of considered plasticizers on the workabilities and strengths of mortars containing calcined marl blended cements were investigated. Calcined marl needs such a research due to it is a relatively novel compared to other supplementary cementitious materials avalilable on the market. The blended cements in the study were obtained by partly replacement (0%, 10%, 30% and 50%) of calcined marl to clinker. Plasticizers used in the test mixtures were added with ratios such as 0.8% (low), 1.2% (medium) and 1.5% (high) to the mixing water. Density, slump-spread, ultrasonic pulce velocity (UPV) and strength on mortar samples were determined. According to the parameters examined in the study, the compressive strengths of mortars containing calcined marl blended cement improved up to 30% replacement ratio. And, the optimum compatibility between plasticizers and blended cements with calcined marl was determined as polycarboxylate ether (PCE) plasticizer with up to 1.2% usage ratio.

Keywords: calcined marl, blended cement, plasticizer, compatibility

Kalsine Marn Katkılı Çimentoya Uygun Akışkanlaştırıcının Belirlenmesi

Öz

Kalsine marn (CM) katkılı çimento ile naftalin sülfonat-formaldehit (NSF), vinil kopolimer (VCP) ve polikarboksilat eter (PCE) gibi farklı kökenli üç akışkanlaştırıcı arasındaki uyumluluk araştırması yapılmıştır. Dikkate alınan akışkanlaştıcıların kalsine marn katkılı çimento içeren harçların işlenebilirlikleri ve dayanımları üzerindeki etkileri incelenmiştir. Kalsine marn, piyasada bulunan diğer tamamlayıcı çimentolu malzemelere kıyasla nispeten yeni olması nedeniyle böyle bir araştırmaya ihtiyaç duymaktadır. Çalışmadaki katkılı çimentolar, kalsine marnın klinkere kısmen (%0, %10, %30 ve %50) yerdeğiştirilmesi ile elde edilmişlerdir. Deney karışımlarında kullanılan akışkanlaştırıcılar, karıştırma suyuna %0,8 (düşük), %1,2 (orta) ve %1,5 (yüksek) gibi oranlarda eklenmiştir. Harç numunelerinde yoğunluk, çökme-yayılma, ultrasonik darbe hızı (UPV) ve dayanımları belirlendi. Çalışmada incelenen parametrelere göre, kalsine marn katkılı çimento içeren harçların basınç dayanımları %30 yerdeğiştirme oranına kadar iyileşmiştir. Ayrıca, kalsine marn katkılı çimentolar ile akışkanlaştırıcılar arasındaki optimum uyumun %1,2' ye kadar kullanım oranına sahip polikarboksilat eter (PCE) akışkanlaştırıcısı olduğu belirlenmiştir.

Anahtar Kelimeler: kalsine marn, katkılı çimento, akışkanlaştırıcı, uyumluluk

Sorumlu Yazar / Corresponding Author: Yasemin Akgün ysmakgun@gmail.com

Introduction

Cement is a building material that needs to efficiency usage of energy and to improvement as environmental in terms of production techniques. To produce a ton of cement requires approximately 80 to 100 kWh of electrical power. Also during its production processes release average 0.95 tons of CO2 (Bildirici & Ersin, 2024). The current targets of the cement industry are to reduce these values. The easiest and most effective way to meet this need is to produce blended cement using high ratios of clinker substitute material. Thus, due to less clinker use, energy savings and low CO2 emissions action targets could be achieved. As seen, the cement industry has a global impact on CO2 emissions (Andrew, 2018; Xiang et al, 2024; Liu et al, 2024). Cement is also an important product that is closely related to the economic development of countries. Lately, many countries of the world have increasingly been produced blended cements with lower clinker ratios. (Guo et al., 2024). Naturally, the high replacement demand in blended cement brings plasticizer demand. In this case, compatibility between plasticizer and blended cement is new problem that needs to be solved. Also, one of the important problems in these applications is the fewness of research of compatible plasticizer to mineral additive type used for blended cements. As known, the solution of this compatibility problem is generally neglected in the literature studies. As also seen from studies, (El Bitouri et al., 2022; Elistratkin et al., 2019; Kermani et al., 2024; Kulshreshtha et al., 2023; Nitin et al., 2024) cement-plasticizer incompatibility is caused by both plasticizer-origin and cement-origin factors. For this reason, researches on especially blended cements and compatible plasticizers to its should be carried out together. The manufacturers of plasticizer industry should design products by focusing to experimental studies and considering all the factors in terms of compatibility.

Fly ash, furnace slag, and silica fume are additive materials for blended cements. These materials will always be needed in cement production due to their environmental impact, energy saving and performance improvement aims. However, even today cement factories already consume approximately 90% of the available blast furnace slag (Moukannaa et al., 2020). These current materials cannot meet increasingly demand in the future. Therefore, recently, interest in calcined clays has been increasing (Tironi et al., 2013) Because, clays have proven to be abundantly available almost everywhere in the world. And, they show high pozzolanic activity when they are calcined at appropriate temperatures (Bahhou et al., 2024).

Natural marl is a material that contains clay and limestone in certain percentages (35-85% clay and 15-65% limestone) and is as called “clay contaminated” by limestone within the clay group (Bahhou et al., 2021). But, when it is calcined at appropriate temperature, it shows high pozzolanic activity. Also, calcined marl with high potential waiting to be discovered is a novel alternative natural SCM for Portland cement clinker that exhibits synergistic reactions thanks to its clay and limestone contents in its natural structure (Danner, 2018). To summarise, calcined marl offers a tremendous potential as SCM that can be replaced with cement clinker.

In previous studies, the blended cements containing calcined marl used with high replacement ratios performed quite well in terms of strength and durability (Danner et al, 2015; Ng &,Justnes, 2015; Rakhimova et al., 2021; Sposito et al., 2022). But the using of calcined marl significantly decreases the flow of the cement due to high absorption of water. Therefore, when calcined marl is used with high replacement, it should be used with a suitable plasticizer. It needs to study on the compatibility of plasticizers to be used with the cement. In the literature, the research on compatibility between plasticizer and calcined marl blended cements is very few. This is related to the fact that calcined marl is still novel and non-common SCM.

Through this study, it is aimed to obtain scientific data that will provide the commonly use with optimum values of local-natural marl as a novel SCM for blended cement productions. In the author's previous studies, pozzolanic activity of calcined marl, some properties of blended cements with calcined marl and mortars containing blended cements with calcined marl were extensively studied (Akgün, 2019; Akgün, 2020; Akgün, 2021). The scope of this study is to examine the compatibility

between blended cements containing calcined marl and plasticizers. In this study, the physical property, compressive strength, ultrasonic pulse velocity (UPV) and slump-spread tests on the mortar samples produced with blended cements containing calcined marl and plasticizers with different orgin were performed. All results of test series were examined comparatively with each other and reference samples.

Materials and Methods

Plasticizers affect the physical and mechanical properties of cementitious systems. Many studies have been conducted on the compatibility of plasticizers with different cements. In these studies, it was concluded that cement–plasticizer compatibility depends on the change in the chemical and physical properties of the concrete components (Tunc, 2024; Kobya et al., 2024; Murugan et al., 2024). However, plasticizier-cement compatibility is still seen as an unknown. The objective of the study is investigated how compatibility between blended cements containing calcined marl and chosen plasticizers affects workabilities and strengths of produced samples.

The CEM I 42.5 R type Portland cement in accordance with EN 197-1 (CEN, 2012) standard was used as binder. The some properties of cement obtained by the manufacturer are given in Table 1.

Table 1. Properties of CEM I 42.5R.

Chemical Properties		Physical Properties		Clinker Components (%)	
Sulfur Trioxid (SO3) (%)	3.02	Specific Gravity (g/cm^3)	3.12	C_3S	54,78
Chloride (Cl^-) (%)	0.0252	Specific Surface (cm^2/g)	3210	C_2S	26,11
Loss on Ignition (%)	3.06	Initial Setting Time (min.)	170	C_3A	11,83
Insoluble Residue (%)	0.76	Volume Expansion (mm)	2.0	C_4AF	0.91
Mechanical Properties					
2 Days Compressive Strength (MPa)		32.30			
28 Days Compressive Strength (MPa)		53.00			

It was used natural calcined marl as replacement material with clinker in production of blended cement. Natural marl was obtained from Sinop/Erfelek, Black Sea Region of Türkiye. The total percentage of Si, Al and Fe oxides in the chemical content of natural marl is 76.43% by weight. Its specific surface area and density is 4630 cm2/g and 2.70 g/cm3, respectively. These properties indicate that natural marl has pozzolanic activity according to TS 25 (TSE, 2011). However, natural marl must be calcined at the optimum temperature for its pozzolanic activity. To calcine natural marl at the most suitable temperature, as stated in many technical literature if clay contain marl it should be calcined at least 800 °C (Tironi, 2013). Likewise, optimum calcination temperature of marl was determined by TGA method as 8000C in the author's previous study (Akgün, 2019). Therefore, natural marl was calcined at 800 °C. CEN standard sand defined with EN196-1 (CEN, 2016). was used as aggregate in production of samples. The specific grain size distribution CEN Standard sand ranges between 0.08 and 2.00 mm.The sieve residue in % of CEN standard sand for 2.00, 1.60, 1.00, 0.50, 0.16 and 0.08 squared mesh sizes in mm is 5.28, 33.82, 67.35, 86.83 and 99.71, respectively. The specific gravity and water absorption capacity of CEN standard sand were obtained as 2.64 and 0.6% by mass, respectively, in accordance with the EN 1097-6 (CEN, 2022) standard. The maximum moisture content is 0.2%. The sand is portioned in bags of 1350 (± 5) g. Three types of blended cements in three different replacement ratios (10%, 30% and 50%) were used in preparing mortar mixes. Chemical admixtures are used in practice for many purposes such as gaining higher strength by reducing the water/cement ratio, reducing the amount of cement in mass concrete to reduce the heat of hydration, or ensuring the same workability and easy settling (Plank et al, 2015). In this study, investigations were carried out on determination of compatible plasticizier to improve of parameters such as workability, physical property, ultrasonic pulse velocity and strength of test samples produced by blended cement with calcined marl and different plasticiziers. The three different plasticizers were added to the mixing water in proportion (0.8%, 1.2% and 1.5%) to the cement weight. According to American Concrete Institute (ACI), plasticizers could be classified in terms of chemical content as sulphonate melamine

formaldehyde, sulphonate naphthalene formaldehyde, modified lignosulphonates, and copolymers contain sulphonic and carboxyl groups (ACI, 1987). The study was carried out comply with this classification. In tests, in order to determinate the effectiveness of mortar mixtures prepared with grinded natural marl, different plasticizers such as polycarboxylate ether (PCE), naphthalene formaldehyde sulfonate (NSF) and vinyl copolymer (VCP) were added to the mixing water. The selected plasticizers are brown in color, liquid form and comply with EN 934-2 (CEN, 2013). They were used by adding 0.8% (low), 1.2% (medium) and 1.5% (high). The specific gravity of the plasticiziers are 1.05 g/cm3, 1.12 g/cm3 and 1.14 g/cm3, respectively. All of tests were performed at the end of curing period (28days). The mortar samples without calcined marl and plasticizers were also cast as the comparison samples. The city mains water was used as mixing water. A view of calcined natural marl samples (a), standard sand (b) and plasticiziers (c) are seen in Figure 1.

Figure 1. A View of Calcined Natural Marl Samples (a), Standard Sand (b) and Plasticiziers (c)

SEM (Scanning Electron Microscope) investigations were carried out in Ordu University Central Research Laboratories to define the general surface morphologies of natural marl and marl samples calcined at 800oC. SEM examinations of natural marl and calcined marl samples with calcination process were carried out by grinding as finer than Portland cement fineness for pozzolanic activation purposes. In order for the samples to turn into conductive material as required by SEM examinations, the surface of the marl samples on the carbon band of the device called "sputter" was gold plated in standard sizes. In this study, natural marl calcined at 800°C was replaced in the ratios 0%, 10%, 30% and 50% with clinker. And then, mortar samples were produced with the obtained blended cements. In the study, mini slump-spread tests were carried out in accordance with (EN 12350-8) (CEN, 2019) to determine the compatibility between blended cement containing calcined marl and plasticizers in terms of workability. The high amount of slump-spread indicates that the mortar has a high ability to move under its own weight. In this regard, the greater the amount of slump-spread the greater the degree of workability. On the other hand, it was carried out physical property (EN 12390-7) (CEN, 2019), ultrasonic pulse velocity (ASTM C597-22) (ASTM, 2023) and compressive strength with (EN 196-1) (CEN, 2016) tests on mortar samples to determine the compatibility between cement containing calcined marl and plasticizers in terms of strength. The tests were carried out “Building and Material Laboratory” of Technical Sciences Vocational School in Ordu University. The samples were 28 days during the strength tests. The results obtained were compared with each other. The labels of test series are given in Table 2. The amounts of components included in the mortar mixtures are given in Table 3. Mortar samples were produced as a series of 40 tests with 50x50x50mm cube samples under laboratory conditions with a temperature of 20±2ºC and relative humidity of 60±5%. The samples were 28 days at the time of the tests. The tests were carried out at Ordu University, Vocational School of Technical Sciences, Construction and Materials Laboratory. Some images of production and tests are given in Figure 2.

Table 2. The Labels of Test Series

The labels of test series	Description
CM0	0% marl and 0.8%-1.2%-1.5% ratios of plasticiziers
CM0PCE0.8, 1.2, 1.5	PCE; Polycarboxylate Ether
CM0NSF0.8, 1.2, 1.5	NSF; Naphthalene Sulphonate–Formaldehyde
CM0VCP 0.8, 1.2, 1.5	VCP; Vinyl Co-Polymer
CM10	10% marl and 0.8%-1.2%-1.5% ratios of plasticiziers
CM10PCE0.8, 1.2, 1.5	PCE; Polycarboxylate Ether
CM10NSF0.8, 1.2, 1.5	NSF; Naphthalene Sulphonate–Formaldehyde
CM10VCP0.8, 1.2, 1.5	VCP; Vinyl Co-Polymer
CM30	30% marl and 0.8%-1.2%-1.5% ratios of plasticiziers
CM30PCE0.8, 1.2, 1.5	PCE; Polycarboxylate Ether
CM30NSF0.8, 1.2, 1.5	NSF; Naphthalene Sulphonate–Formaldehyde
CM30VCP0.8, 1.2, 1.5	VCP; Vinyl Co-Polymer
CM50	50% marl and 0.8%-1.2%-1.5% ratios of plasticiziers
CM50PCE0.8, 1.2, 1.5	PCE; Polycarboxylate Ether
CM50NSF0.8, 1.2, 1.5	NSF; Naphthalene Sulphonate–Formaldehyde
CM50VCP0.8, 1.2, 1.5	VCP; Vinyl Co-Polymer

Table 3. The Amounts of Components in the Mortar Mixtures

Components (kg/m^3)	M0	M10	M30	M50
Portland Cement	350	315	245	175
Calcined Marl	-	35	105	175
Water	175	175	175	175
Water/Cement	0.50	0.50	0.50	0.50
Standard Sand	1350	1350	1350	1350
Plasticizier ratios (%)				
0%	-	-	-	-
0.8%	2.80	2.80	2.80	2.80
1.2%	4.20	4.20	4.20	4.20
1.5%	5.25	5.25	5.25	5.25

Figure 2. A View for Some of Production and Test Methods

Results and Discussions

The findings obtained from the study on the compatibility of different plasticizers to blended cements containing calcined marl are outlined below.

SEM photographs showing the general surface morphology for natural marl and calcined marl samples are given in Figure 3. It could seen internal micro structure, grain and void structure of natural and calcined marl samples from SEM photos. The amorphous structures of natural and calcined marl samples and the changes in grain structure after calcination are observed.

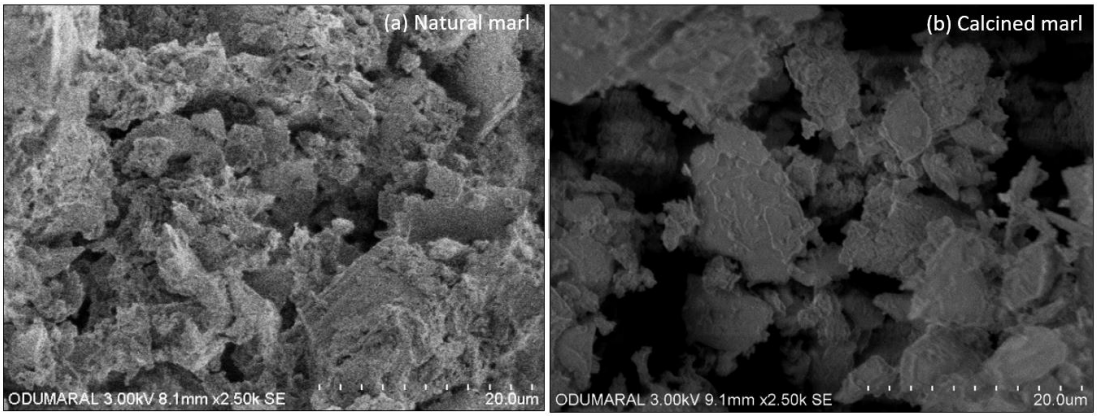

Figure 3. SEM Photos of Natural (a) and Calcined (b) Marl Samples

The variation graphs of average densities (Figure 4), slump (Figure 5), spread values (Figure 6), ultrasonic pulse velocities (Figure 7) and compressive strengths (Figure 8) for replacement, type of plasticizer and ratios of mortars containing calcined marl blended cement are given below.

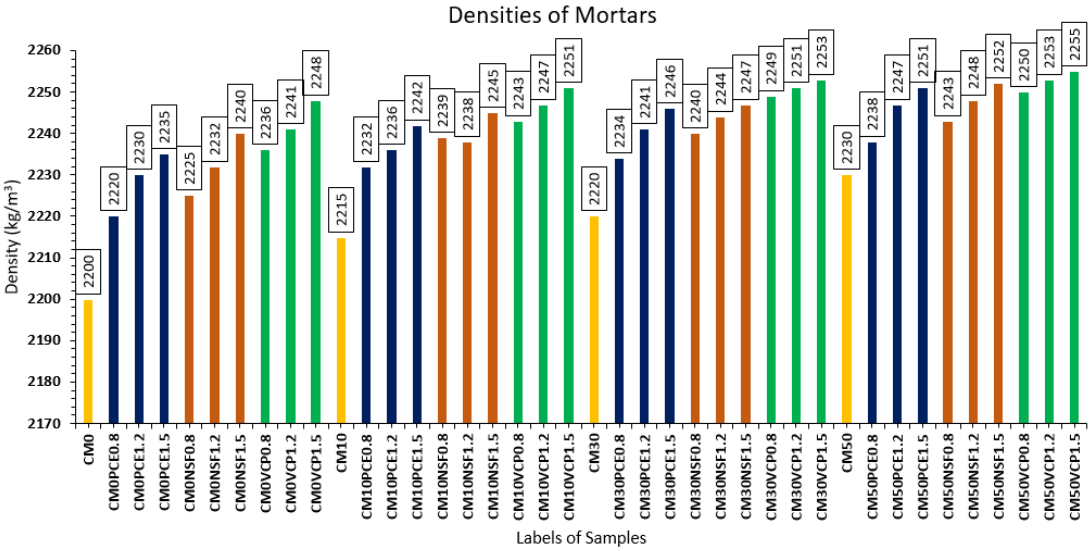

Figure 4. Densities of Mortar Samples

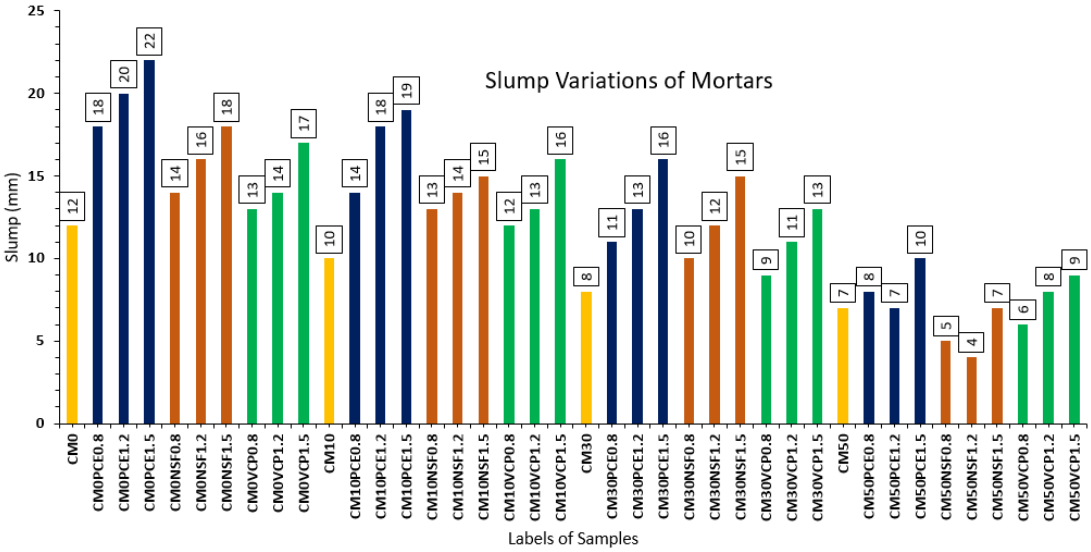

Figure 5. Slump Variations of Mortar Samples

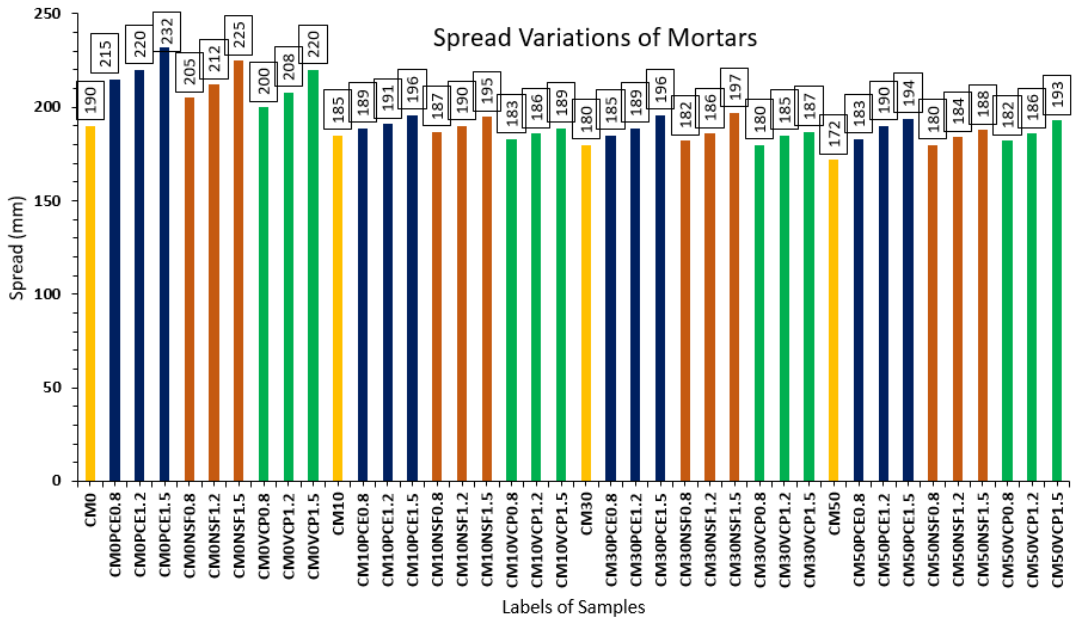

Figure 6. Spread Values of Mortar Samples

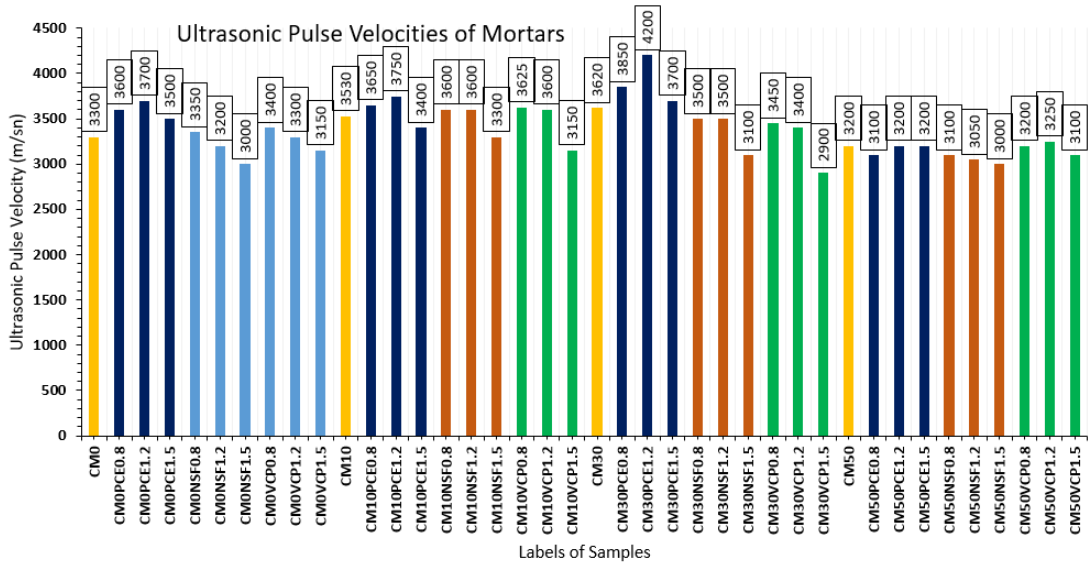

Figure 7. Ultrasonic Pulse Velocities of Mortar Samples

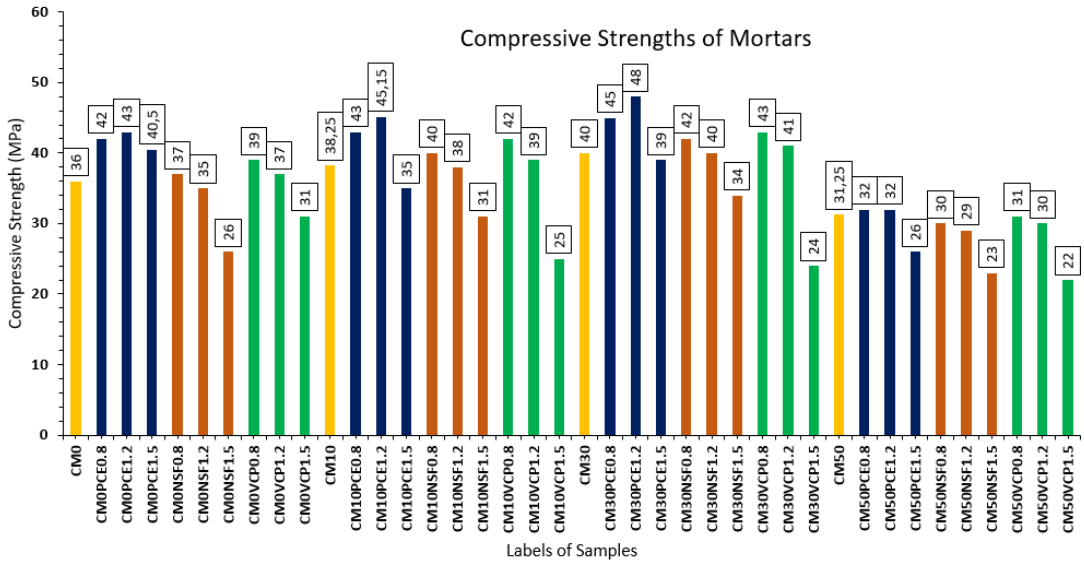

Figure 8. Compressive Strengths of Mortar Samples

According to variation graphs of densities, the variations in the densities of the samples in the series (CM0, CM10, CM30 and CM50) with calcined marl replacement but without plasticizer increase as the amount of calcined marl replacement increases. This is a result of the voidless internal structure due to the filler effect caused by the mineral additive being ground below the cement fineness.

According to the slump-spread values of mortar samples, it was observed that the slump-spread values in all of mortar mixtures decreased with increase in calcined marl replacement. And, as the plasticizer usage ratio increased, the slump-spread values increased. Among the plasticizers used in the study, PCE plasticizer is the most compatible plasticizer with calcined marl blended cements in terms of workability.

All test program series were compared in terms of only strength improvements. It was more higher 11.11% in those without plasticizer (for CM30), 19.44% in those without calcined marl but with plasticizers (for CM0PCE1.2) and 33.33% in those with both calcined marl and plasticizer (for CM30PCE1.2) than strengths in CM0 series. According to these ratios, it is thought that the use of plasticizers in designs using mineral additives improves the pore structure by providing regular distribution of the mixture and also improves the final product strength (Cho et al., 2005; Plank et al.,

2008). The variations in densities support this mechanism related to the development of compressive strength.

In this study, the optimum calcined marl replacement ratio was determined as 30%. Some strength decreases were observed in replacement ratio of 50% calcined marl. However, the strengths in the study were determined on 28-days samples. Therefore, there is also an expectation that the late-age strengths of the samples will improve with the late-age additional binders due to the pozzolanic activity of the calcined marl used in the mixtures (Danner et al., 2012).

The compressive strengths of samples were compared in terms of type of plasticizer and usage ratio. It is seen that the most suitable plasticizer is PCE in terms of higher compressive strengths for both the series without marl and the series containing NS and MP plasticizers. These increases in strength are more apparent for the 0.8% and 1.2% ratios. This is because water bleeding and segregation were observed during the production of mortars containing 1.5% PCE and calcined marl.

On the other hand, the UPVs of samples were compared. The compressive strength and UPVs of the samples show similar tendency. The internal structural variations of mortar samples support the compressive strength test results. This expected situation from literature studies is an indication that the production of test samples was carried out in accordance with the standard conditions. It also shows that the determination method with the UPV device which is one of the non-destructive testing methods for determining the quality of concrete can be used to provide data for the uniaxial compressive strength determination method which is one of the destructive testing methods.

Conclusions and Recommendations

The conclusions obtained from findings of the study on the compatibility of different plasticizers to blended cements containing calcined marl are,

- The density, slump-spread, UPV and compressive strengths of mortar samples produced by using calcined marl and CEM I 42.5R type cement showed variations according to the origin of used plasticizers.
- According to the results and discussions, it was determined that polycarboxylate-based (PCE) plasticizer was more effective than NS and MP plasticizers under the conditions of this study in terms of compatibility to blended cement containing calcined marl. Literature supports the compatibility of PCE plasticizer for the dispersion of calcined clay blended systems (Ng & Justnes, 2015; Li et al, 2021).
- The test results carried out on mortar samples containing calcined marl blended cement in terms of workability and strength showed that PCE is the plasticizer that compatible with calcined marl blended cements up to 30% replacement ratio and its usage ratio is up to 1.2%. Because, it was observed water bleeding and segregation during the production of mortars added PCE at 1.5% ratio.
- Here, it should be emphasized that cement-plasticizer interaction is important in terms of fresh concrete properties and strength, therefore cement-plasticizer compatibility tests should be carried out before application.

Author Contribution

The authors co-wrote, read and approved the manuscript.

Ethics

There are no ethical issues regarding the publication of this article.

Conflict of Interest

The authors declare that they have no conflict of interest.

ORCID

Yasemin Akgün https://orcid.org/0000-0002-4178-5233

Murat Usta https://orcid.org/0009-0000-4818-0969

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Effect of Vermicompost on Quality Index, Oxidation and Colour Ordinates of Hazelnut Oil

Ali Turan[1]

[1] Giresun University, Hazelnut Specialization Coordinatorship, Giresun

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Abstract

The present study aims to address this knowledge gap by investigating the impact of vermicompost (3-5 kg/Ocak; VM1 and VM2, respectively) on the linolenic/linoleic acid ratio (n3/n6), polyunsaturated/monounsaturated fatty acid ratio (PUFA/MUFA), monounsaturated/unsaturated fatty acid ratio (MUFA/SFA), and oil quality index values; Atherogenicity (AI) and thrombogenicity index (TI) values, hypocholesterolemic/hypercholesterolaemic fatty acids ratio (H/H) values and stability index (SI) value; fat oxidation parameters; oleic/linoleic acid ratio (O/L), free fatty acidity value (FFA, oleic acid %), rancimate value (RV, h) and colour properties. The lowest AI value was found in the VM1 treatment (0.05), while the highest value was found in the VM_2 and control (0.06) treatments. The highest H/H (16.92) and SI (7.24) values were also observed in the VM_1 treatment. Conversely, the highest RV and lowest FFA values were determined in the VM_2 treatment, while variability was observed in terms of colour characteristics. The application of VM_2 was found to be partially more prominent in terms of some traits, and when all these data were evaluated in general, it was concluded that it is of great benefit to continue the studies on vermicompost.

Keywords: fatty acid profiles, free fatty acids, oxidation of oil

Solucan Gübresinin Fındık Kalite İndeks Değeri, Oksidasyon ve Renk Özellikleri Üzerine Etkisi

Öz

Bu çalışma, solucan gübresinin (3-5 kg/Ocak; sırasıyla VM_1 ve VM_2) linolenik/linoleik asit (n3/n6) oranı, çoklu doymamış/tekli doymamış yağ asidi oranı (PUFA/MUFA), tekli doymamış/doymamış yağ asidi oranı (MUFA/SFA) ve yağ kalite indeksi değerleri üzerindeki etkisini belirlemek amacıyla yürütülmüştür. Çalışmada, aterojenisite (AI) ve trombojenisite indeksi (TI) değerleri, hipokolesterolemik/hiperkolesterolemik yağ asitleri oranı (H/H) ve stabilite indeksi (SI) değeri ile yağ oksidasyon parametreleri; oleik/linoleik asit oranı (O/L), serbest yağ asitliği değeri (FFA, oleik asit %), ransimat değeri (RV, h) ve renk özellikleri incelenmiştir. En düşük AI değeri VM_1 uygulamasında (0,05) bulunurken, en yüksek değer VM_2 ve kontrol (0,06) uygulamalarında bulunmuştur. Diğer yandan en yüksek H/H (16,92) ve SI (7,24) değerleri ise VM_1 uygulamasında gözlenmiştir. Buna karşılık, en yüksek RV ve en düşük FFA değerleri VM_2 uygulamasında kaydedilmişken, renk özellikleri açısından uygulamalar arasında değişkenlik göze çarpmıştır. VM_2 uygulamasının bazı özellikler bakımından kısmen daha ön plana çıktığı görülmüş olsa da tüm bu veriler genel olarak değerlendirildiğinde solucan gübresi ile ilgili çalışmaların devam ettirilmesinde büyük fayda olacağı sonucuna varılmıştır.

Anahtar Kelimeler: yağ asitleri kompozisyonu, serbest yağ asitleri, yağ oksidasyonu

Sorumlu Yazar / Corresponding Author: Ali Turan ali.turan@giresun.edu.tr

Introduction

Hazelnut (*Corylus avellana* L.) is a significant crop, ranking among the most widely cultivated hard-shelled fruits worldwide (Islam, 2018). The demand for hazelnuts has been steadily rising, driving continuous expansion in global production. These nuts are consumed in various forms, including raw and roasted, and find application in diverse industries, particularly the chocolate sector (Korkmaz et al., 2021). Hazelnuts are recognised as nuts with a high fat content (~60%) and are also abundant in oleic, linoleic and palmitic fatty acids (Müller et al., 2020; Negrillo et al., 2021). In addition, hazelnuts are considered to be adequate in macronutrients such as protein (~17%) and micronutrients such as vitamins B, E and tocopherol. Additionally, it is well-documented that the nuts of the hazelnut tree contain notable quantities of potassium, manganese, calcium, magnesium, iron, zinc, copper, manganese and boron (Müller et al. 2020; Negrillo et al., 2021; Özkutlu et al., 2016; Özkutlu et al., 2022). Consequently, hazelnuts are widely regarded as functional foods, which is evidenced by their ability to provide substantial health benefits to humans due to their high content of bioactive components, including flavonols, phenolic acids, tocopherols and sterols (Pelvan et al., 2018).

Hazelnuts, conversely, are distinguished by their elevated fat content, with triacylglycerols constituting the primary component. Additionally, the presence of substantial levels of monounsaturated fatty acids confers upon hazelnuts a notable nutritional value, coupled with a considerable sensitivity to autoxidation and/or degradation reactions under enzymatic catalysis. The formation of secondary fat oxidation products, especially carbonyl derivatives, poses a significant challenge for confectionery industries and can also affect the sensory properties of hazelnuts (Rosso et al., 2021). Consequently, numerous studies have been conducted and are ongoing to define the fat fraction of hazelnuts and to examine its changes during the storage period (Turan, 2018a).

It is widely accepted that oil oxidation is the primary factor contributing to the deterioration of high-fat foods, such as hazelnuts. Consequently, it is imperative to ascertain the shelf life of foods with high fat content. The shelf life of hazelnuts is predominantly influenced by the temperature and moisture content of the storage conditions (Hosseini et al., 2014; Shafiei et al., 2020; Turan, 2018b). The impact of fat oxidation on food products is twofold; firstly, it affects their sensory properties and secondly, it has a detrimental effect on human health, including the risk of developing pathogens such as cancer (Kalyanaraman, 2013). Unsaturated oleic and linoleic fatty acids are known to be sensitive to fat oxidation, therefore it is imperative that cultural practices in hazelnut production are carried out correctly and in a timely manner (Turan, 2019). Notably, fertilisation practices have been identified as a crucial aspect that is often overlooked in hazelnut cultivation. This is primarily due to the reluctance of hazelnut producers, who constitute a paradigm of traditional farmer structures, to apply fertiliser in accordance with soil analysis (Turan, 2023). As a consequence, yield and quality losses are frequently experienced.

The yield and quality of hazelnut production can be adversely affected by several factors. Firstly, the topography of the land, which is characterised by hills, can impede the efficient application of fertilisers, as the soils tend to be shallow. Secondly, the agricultural practices of the producers can also be a contributing factor. This includes errors in pruning, a lack of emphasis on bottom shoot cleaning, inadequate weed removal, and erroneous fertilisation techniques. Nitrogen fertilisers are among the most commonly used fertilisers in hazelnut production (Özkutlu et al., 2020), and consequently, deficiencies in other fertilisers inevitably lead to yield loss (Aydemir et al., 2023). Conversely, problems in accessing farm manure can be experienced from time to time. Another method of adding organic matter to the soil in the absence of farm manure is green manuring. Green manure plants suitable for hazelnut orchards include vetch, wild peas and oats, which should be sown in a ring-shaped band extending 50-100 cm beyond the projected branches in sloping terrain. This practice should be implemented in all gardens situated in flatlands, and the plants should be mowed and incorporated into the soil prior to flowering in spring (Turan, 2023).

In addition to the aforementioned fertilisers, vermicompost has recently been recommended (Tarakçıoğlu & Bender Özenç, 2022). However, the number of studies carried out on the effect of vermicompost on the yield and nut quality of hazelnuts is very limited. Therefore, the present study was undertaken to determine the effect of vermicompost on the fruit quality of the Tombul hazelnut cv in the country of Turkey. It is hypothesised that the data obtained will firstly contribute to the hazelnut economy and then guide future academic studies.

Material and Methods

Samples

The research was conducted between 2018 and 2020 in a ~30 years old, 5 da orchard of Tombul cv in Ülper village, central of Giresun province (40°51´34.52˝N, 38°26´05.10˝E, and altitude 233 m). The study was planned as 5 replications and was carried out with 3 ocak (at least 3 or more trunk) in each replication. The orchard was arranged as 5×5 between rows, 5×5 above rows, 5 branches/ocak and 50 ocak/da. Soil samples were collected from 0–20 cm and 20–40 cm depths, and analyzed followed by application of fertilization program (Duyar & Özenç, 2013). The soil analysis showed soil with a *pH* of 5.64, K_2O of 33.14 kg/da, P_2O_5 of 0.29 kg/da, lime of 0.47%, organic matter of 5.23%, total salt of 0.01%, saturation of 62.04%. The vermicompost is obtained from Yavuz Food Industry and Trade Inc. (Giresun, Turkey; 40°56´31.17˝N, 38°10´28.32˝E, and altitude 4 m). The vermicompost *pH* was 7.37 and electrical conductivity was 3.06 ms/cm, with a moisture rate of 43.02%. It consisted of organic carbon of 13.89%, organic matter of 31.11%, organic nitrogen of 2.00%, P_2O_5 of 0.20%, and K_2O of 1.11%. In the study, 150–250 kg/da (3–5 kg/Ocak; VM_1 and VM_2, respectively) of vermicompost recommended for hazelnut was used (Figure 1).

Figure 1. Application of Vermicompost for Hazelnut Orchard

The control treatment was based on traditional farmer practice, and these procedures were carried out according to Öztürk et al. (2022). Harvesting procedures were made according to method of Turan (2018a). The hazelnuts that reached a moisture content of ~25%, were harvested by hand, separated from their husks by hand, and left to dry naturally in the shade (Average temperature: 24℃, average sunshine duration: 3.5 h, average rainfall: 85 mm, and moisture value: 68%), and the drying process lasted ~18 days. After the samples were reduced to 6% moisture content, they were stored in a refrigerator at ~5℃ and ~65% relative humidity until the oil extraction.

Fatty Acid Composition

The extraction of hazelnut oil was accomplished through the utilisation of a cold press oil extraction system, while the subsequent analysis of fatty acids was performed via gas chromatography. This method was employed to ascertain the fatty acid content, with the subsequent generation of fatty acid methyl esters adhering to the techniques outlined by Turan (2018a) and Turan (2019), with minor modifications to align with the methodology established by Turan (2018b).

Quality Index

The values for the fat quality index were determined using the methods outlined by Bezerra et al. (2017) to calculate the atherogenicity (AI) and thrombogenicity index (TI) values, as well as the hypocholesterolemic/hypercholesterolemic fatty acids ratio (H /H) values were obtained with fatty acids formulation according to Fernandes et al. (2019) and Turan (2021). The stability index (SI) was described by Özdemir et al. (2001).

Oxidation

Free fatty acidity (method Ca 5a-40), and peroxide value (method Cd 8-53) were determined using AOCS standard method (AOCS, 2004). The Rancimat value was determined using the Rancimat 743 device (Velasco, 2004), and the iodine value (IV) was calculated using the percentage of fatty acids (Turan, 2021).

Clour Ordinates

The colour of hazelnut kernels was measured in accordance with the methods outlined by Mexis and Kontominas (2009) and Turan (2022). The chroma value, which is indicative of the tone of the product colour and ranges from low values in pale colours to high values in vivid colours, was determined in accordance with the methods outlined by Polatcı and Tarhan (2009). The hue angle (h^o) value refers to the colours corresponding to each angle in a 360° colour gradient (Polatci & Tarhan, 2009; Taşova & Güzel, 2017).

Statistical Analysis

The experimental phase of the study was conducted utilising a randomised blocks design, with each experimental unit being replicated thrice. The subsequent analysis involved the determination of descriptive statistics, which were then processed using SPSS v. 22.0 (Armok, New York: IBM Corp.). The execution of statistical tests was facilitated by SAS–JAMP v. 10.0. The identification of significant differences was achieved through the implementation of a t-test, with a significance level of $P < 0.001$.

Results and Discussion

Quality Indices of Hazelnut Oil

Atherogenicity (AI) and thrombogenicity index (TI) values, which are indicators of the global dietary quality of fats and their potential impact on the development of coronary diseases, are considered as a quality indicator of fatty acid content (Durmuş, 2019; Telahigue et al., 2019). These IA and IT index values proposed by Turan (2022) can better characterize the potential of fatty acids. While low values are considered favorable for human health, high values are considered harmful.

IA and IT values >1 have been reported to be harmful for human health (Stancheva et al., 2014). Musalima et al. (2019) reported that if the IT value is >1, blood clots form within blood vessels. Therefore, it is desirable that these properties are close to zero. In our study, the lowest IA value was obtained with VM_1 (0.05) treatment and the lowest IT value was obtained with VM_2 (0.44) treatment (Table 1), and these differences were found to be significant ($P<0.001$). The H/H ratio can be used to obtain information about the effect of fatty acids on the cholesterol mechanism and to determine the cholesterolemic effect index of the fat source (Fernandes et al., 2019).

Table 1. Quality Index of Different Cultivation Practices of Hazelnut

Parameters	Nut samples			Sign.
	VM_1	VM_2	C	
Linolenic/Linoleic acid	0.01±0.00b	0.01±0.00b	0.02±0.00a	**
PUFA/MUFA	0.11±0.00a	0.10±0.00c	0.11±0.00b	***
MUFA/SFA	1.17±0.00a	0.94±0.00c	1.13±0.00b	***
Atherogenicity index	0.05±0.00c	0.06±0.00a	0.06±000b	***
Thrombogenivity index	0.52±0.00a	0.44±0.00b	0.52±0.00a	***
Hypocholesterolemic/hypercholesterolenic	16.92±0.05a	16.24±0.03c	16.36±0.01b	***
Index of stability	7.24±0.01a	4.73±0.00b	2.91±0.00c	***

*VM: Vermicompost. C: Control. Data represent the mean ± std deviation of triplicates (n=3). Significant level *, **, *** and "ns" mean significance at p≤ 0.05, 0.01, and 0.001, and "not significant", respectively, between cultivation practices and control*

A higher H/H value is associated with a higher proportion of PUFAs and therefore a high H/H value is desirable for human health (Turan 2022; Turan et al., 2022). It is seen from the Table 1 that the highest H/H (16.92) and SI (7.24) values were determined after VM_1 treatment. Turan (2021) reported that H/H value varied from 17.45 to 18.27, IA from 0.16 to 0.23, and IT from 0.15 to 0.16 in Tombul cv. Özdemir (2001) reported that the SI value differed between the varieties and this characteristic was 6.30 in Tombul cv. Our study results showed that VM_1 can be recommended considering the quality index values.

Oxidation of Hazelnut Oil

Oils with a high content of PUFAs are more susceptible to oxidative degradation leading to off-flavors and discoloration. Lipid oxidation is a major cause of degradation of fats and oils. Lipid oxidation results in loss of quality and nutritional value and development of unpleasant flavors. Oxidative stability is known as resistance to oxidation under defined conditions and usually corresponds to a sudden increase in the oxidation rate (Gümüş-Bonacına, 2022). The difference in oxidation parameters between the VM_1 and VM_2 treatment groups was found to be statistically significant (P<0.001) and there was variability between treatments (Table 2).

Table 2. Oil Oxidation Parameters of Hazelnut

	Nut samples			
	VM_1	VM_2	C	Sign.
Parameters				
Oleic/linoleic acid	8.69±0.03c	10.35±0.04a	8.96±0.03b	***
Iodine value	91.42±0.06a	89.75±0.09b	91.54±0.02a	***
Ransimat value	5.63±0.01b	6.08±0.01a	6.14±0.04a	***
Free fatty acid	0.18±0.01b	0.17±0.01b	0.21±0.00a	***

*VM: Vermicompost. C: Control. Data represent the mean ± std deviation of triplicates (n=3). Significant level; *, **, *** and "ns" mean significance at p≤ 0.05, 0.01, and 0.001, and "not significant", respectively, between cultivation practices and control*

While oleic/linoleic (O/L; 10.35) value was high with VM_2 treatment, IV (89.75) and free fatty acids (0.17 %, oleic acid) values were low. On the other hand, the highest free fatty acids (0.21 % oleic acid) and IV (91.54) values were observed after the control treatment. Many studies have been carried out on oxidation parameters in hazelnut (Cui et al., 2022; Turan, 2019) and it has been observed that there is variability in the degree of oxidation of hazelnut oil depending on the processes. In conclusion, although there are some differences, based on these data, it can be said that VM_2 treatment is more effective on the shelf life of hazelnut.

Colour Ordinates of Hazelnut Kernel and Oil

The brightness or darkness of the color is represented by "*L*" and the numerical value of "*L*" varies between 0 and 100. The color gets darker as the value approaches 0 and brighter as it approaches 100. The redness or greenness value of the color is expressed by "*a*," and redness indicates positive values and greenness indicates negative values.

The yellowness or blueness value is symbolized by "*b*" Similarly, when "*b*" is at positive values, the yellowness of the color is dominant, and at negative values, the blueness of the color is dominant. Chroma (*C*) refers to the dominance of pastel tone or vivid tone of the color. As the numerical value of *C* increases, the vividness of the color increases. On the other hand, as the numerical value of *C* decreases, the pastel tone dominates the color. The hue angle (*h°*) represents the angle corresponding to the dominant color of the product (Turan, 2022). As shown in Table 3, the effect of treatments on hazelnut kernels and oil color characteristics was generally not significant (P>0.05), and this effect was similar among treatments for hazelnut kernels and oil. That is, the difference between the treatments in b* and *α* values was found to be statistically significant (P<0.001; Table 3), all other color parameters were found to be similar in terms of hazelnut kernels and oil color characteristics (P<0.05). It can be concluded that the treatments partially affect the color properties.

Table 3. Colour Ordinates of Hazelnut Kernel and Oil

Parameters	Nut samples			Sign.
	VM_1	VM_2	C	
Colour ordinates				
Kernel				
L* (Lightness)	35.71±0.40	34.55±0.14	35.24±0.23	ns
a* (Redness)	3.04±0.02	3.08±0.05	3.07±0.05	ns
b*(Yellowness)	0.22±0.00a	0.23±0.01a	0.09±0.00b	**
Chroma (*C*)	3.05±0.02	3.09±0.05	3.07±0.01	ns
Hue (h^o)	14.03±0.20b	13.57±0.19b	34.10±0.50a	***
Oil				
L* (Lightness)	28.14±0.09	28.39±1.13	27.91±1.07	ns
a* (Redness)	2.14±0.01	2.16±0.01	2.13±0.02	ns
b*(Yellowness)	0.15±0.00a	0.16±0.01a	0.07±0.00b	***
Chroma (*C*)	2.15±0.01	2.17±0.02	2.13±0.01	ns
Hue (h^o)	13.94±0.40b	13.60±0.47b	29.20±0.36b	***

*VM: Vermicompost. C: Control. Data represent the mean ± std deviation of triplicates (n=3). Significant level; *, **, *** and "ns" mean significance at p≤ 0.05, 0.01, and 0.001, and "not significant", respectively, between cultivation practices and control*

Conclusions

This study constitutes the inaugural investigation of its kind in the extant literature on the impact of vermicompost on the quality index values and oxidation parameters of the Tombul cv under Giresun conditions. The study revealed that, while the effect of fertiliser doses varied in general, VM_2 application was found to be more effective in terms of general characteristics, while VM_1 application was found to be more effective in some cases. In terms of colour characteristics, it was observed that there was variability according to the treatments. The findings of this study indicate a clear need for further research to be conducted on the subject of vermicomposting. In light of the evaluations conducted, it was determined that the VM_2 application is the most effective.

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Ethic

There are no ethical issues with the publication of this article.

Conflict of Interest

The author state that there is no conflict of interest.

ORCID

Ali Turan https://orcid.org/0000-0002-2961-6605

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DeepImageSegmentationApp: Deep Learning Application for Image Segmentation

Lütfü Bayrak[1], Kenan Koçkaya[1], Ahmet Çınar[2]

[1]Sivas Cumhuriyet University, Divriği Nuri Demirağ Vocational School, Department of Motor Vehicles and Transportation Technologies, Sivas

[2]Fırat University, Faculty of Engineering, Department of Computer Engineering, Elazığ

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Abstract

There are many methods to examine a specific region or object in images. One of the most important of these methods is image segmentation. Image segmentation involves dividing images (or video frames) into multiple sections or objects. There are many different model architectures developed in the field of image segmentation. In this study, a deep learning-based image segmentation application interface has been developed. The performance of the proposed application has been analyzed on the Covid19 dataset obtained from Kaggle. The performance results of the application are presented comparatively on the U-NET and V-NET models with known accuracy for different system parameters. In the analysis results, it is clearly seen that the V-NET architecture is better than the U-NET architecture. The developed application environment has revealed the difference between the models and the usability of the application environment. This standalone software can be downloaded at: https://github.com/lbayrak/DeepImageSegmentationApp.

Keywords: image segmentation, deep learning, U-Net, V-Net

DeepImageSegmentationApp: Görüntü Segmentasyonu için Derin Öğrenme Uygulaması

Öz

Görüntülerde belirli bir bölgeyi veya nesneyi incelemek için birçok yöntem vardır. Bu yöntemlerin en önemlilerinden biri görüntü segmentasyonudur. Görüntü segmentasyonu, görüntüleri (veya video karelerini) birden fazla bölüme veya nesneye ayırmayı içerir. Görüntü segmentasyonu alanında geliştirilen birçok farklı model mimarisi vardır. Bu çalışmada, derin öğrenme tabanlı bir görüntü segmentasyonu uygulama arayüzü geliştirilmiştir. Önerilen uygulamanın performansı Kaggle'dan elde edilen Covid19 veri kümesi üzerinde analiz edilmiştir. Uygulamanın performans sonuçları, farklı sistem parametreleri için bilinen doğrulukla U-NET ve V-NET modelleri üzerinde karşılaştırmalı olarak sunulmuştur. Analiz sonuçlarında V-NET mimarisinin U-NET mimarisine göre daha iyi olduğu açıkça görülmektedir. Geliştirilen uygulama ortamı modeller arasındaki farkı ve uygulama ortamının kullanışlılığını ortaya koymuştur. Bu bağımsız yazılım şu adresten indirilebilir: https://github.com/lbayrak/DeepImageSegmentationApp.

Anahtar Kelimeler: görüntü bölümlendirme, derin öğrenme, U-Net, V-Net

Sorumlu Yazar/ Corresponding Author: Kenan Koçkaya kkockaya@cumhuriyet.edu.tr

Introduction

Deep learning is a subset of machine learning methods based on artificial neural networks using multiple layers (LeCun et al., 2015). Deep neural networks (DNN) have been successful in many areas such as computer vision (Krizhevsky et al., 2017) or natural language processing (LeCun et al., 2015) in recent years. In academic studies, DNNs have been widely used in many areas, including medical image segmentation, and have shown successful results. Image segmentation is the process of dividing a digital image into multiple parts. In deep learning-based image segmentation processes, masks belonging to these images are usually used together with the images to be processed. This technique provides a much more detailed understanding of the objects in the image. Some studies in the field of deep learning-based image segmentation are as follows; Yong Peng et al. (2023) proposed a cluster boundary segmentation based on convolutional neural networks and watershed algorithm to quickly determine the boundaries of clusters in asphalt mixture CT images. In the study, it is stated that the proposed intelligent image segmentation algorithm gives more accurate results than canny and multi-threshold algorithms in finding the boundaries.

Gupta and Mishra (2024) conducted a deep learning-based image segmentation study on early detection of colorectal cancer. The study presents statistical analysis of Unet, R2Unet, Attention-based Unet, ResUnet, Unet 3+, TransUnet and SwinUnet models based on polyp datasets and performance measurements.

Li et al. (2024) conducted a deep learning-based image segmentation study on the examination of remote sensing (RS) images. In the study, a comprehensive review was made on remote sensing research systems and various specially designed deep learning models.

Dang et al. (2024) conducted a deep learning-based image segmentation study on CVC-ColonDB, a general polyp dataset consisting of 300 images, combining multiple DNN models using ensemble learning.

Zi et al. (2024) conducted a research study on the application of deep learning in the field of medical image segmentation and 3D Reconstruction. The model created in the study they developed is validated by experiments and performance analysis comparisons are made with other deep learning models.

Xu et al. (2024) conducted a deep learning-based image segmentation study on the effect of data quality and quantity of concrete cracks. The study proposes a dataset comparison for pixel-level segmentation of concrete cracks based on the deep learning model.

Zhang et al. (2024) proposed the deep learning-based image segmentation model CNet for the examination of coral reefs on the seabed. The study emphasizes the importance of coral reefs and includes the comparison of the developed model with other models and its performance values for segmentation of reef images.

Liu et al. (2024) proposed the Dual-Path Dual Attention Transformer (DDA-Transformer) model, a deep learning-based image segmentation model, to obtain precise and fast knee joint in robotic-assisted total knee arthroplasty. In the study, the performance and speed of the DDA-Transformer model compared to other models were examined and comparisons were made.

Wang et al. (2024) conducted a deep learning-based image segmentation study to quantify fire power with flame images. In the study, the determination of progress and flame area on fire images was examined and it was aimed to contribute to the development of AI-based fire response systems in the future.

As can be understood from the segmentation studies mentioned above, deep learning-based image segmentation can be used in many areas.

Related Works

Ye et al. (2022) developed an application called DeepImageTranslator for beginners in the field of deep learning-based image segmentation. The developed application was written in the Python programming language and a visual interface was created using the tkinter library.

Deep learning-based image segmentation models are basically related to the knowledge level of the developer. Thanks to experience and knowledge, the deficiencies of the models are seen. In addition, the development of the models is determined by the observations obtained at runtime. For this reason, facilitating the immediate testing of the model codes when they are edited is of great importance in the development of the models and the elimination of their deficiencies. The main purpose of developing this application was to facilitate the basic difficulties encountered in the development of image segmentation models. There are a number of problems encountered while developing a segmentation model. These are;

- Comparing the model with a target model to test its performance
- Eliminating the deficiencies of the model and increasing its success rate compared to the target model
- Testing the performance of the developed model on different datasets
- Comparing the results of the developed model according to different performance criteria and storing the results as numerical data
- Storing visual outputs and reusing them in the future without the need for training
- Enabling the application to re-run the developed model codes in real time
- Comparing the similarity rates of the obtained prediction data on real data are many other problems.

People who work on image segmentation professionally want to intervene in the source code while making the necessary edits and changes. Thanks to the ability to intervene in the source code, developers can work independently of the restrictions of the application environment and perform more successful work.

While developing this application environment, it was aimed for people working in this field to intervene in the codes as they wish and to work comfortably on the datasets they want. For this reason, the application environment was developed with an understandable and easy-to-read coding. Since the target here is professional segmentation model developers, an environment was developed where model development is provided by programmers in order to avoid the limitations of drag-and-drop coding.

Material and Method

In this study, DeepImageSegmentationApp application was developed for deep learning image segmentation of 2D CT images. The application environment was written in Python programming language and user interfaces were created using tkinter and customtkinter libraries. The interface designs were aimed to be user-friendly, simple and understandable. The training and prediction processes of the models were performed using TensorFlow and Keras. While developing the application environment, it was aimed to eliminate the following problems with deep learning image segmentation. These are;

- The inability to run different models sequentially and obtain the results before the training of all models is completed
- The ability to store the results of model trainings based on different parameters without the need for retraining
- The ability to visually compare the prediction data with the real data
- The ability to dynamically reflect the graphical results and include them in the comparison when a different model training is performed

- The ability to easily separate the training and test data by partitioning within the entire dataset
- The ability to create different versions of the developed models
- The ability to compare the data of the different developed versions without the need for constant rerunning and the ability to store the numerical and visual results of the achievements
- The ability to create and run a different version by intervening in the code at runtime, and many more elements could be included.

In order to eliminate the problems and difficulties mentioned above while developing the application and to make it easy to use, the application environment is basically built on three interfaces. These are;

1. Main application environment (UserInterface)
2. Visual interface for comparing test data with prediction data (FigureInterface)
3. Visualization of training outcomes (DashboardInterface).

Loading Data

The first problem encountered in studies on image segmentation is that models are trained on different datasets. The first problem encountered in studies on different datasets is that the datasets are not at a suitable scale for training the model. Another problem encountered is separating the training and test data on the datasets.

A module was developed so that the application environment can work on the desired datasets. In the developed module, the processes of converting the data to the desired format and dimensions are carried out. The data loading process is carried out in the following stages in order to eliminate the difficulties that may be encountered on different datasets.

1. Determining the data path
2. Retrieving images from the data path
3. Rescaling the images
4. Converting the scaled images into Numpy lists as numerical matrices
5. Arranging the models for use.

Here, if desired, the images can be output and stored as numerical data. This part is left to the user's request. The parts related to the storage of numerical data depending on the user's request have been developed and made available within the application environment. The application environment, which was basically developed on 2D image data, can be easily adapted and used for 3D image data.

Main Application Interface (UserInterface)

The main application interface in Figure 1 is the interface environment where segmentation models are dynamically loaded into the system and trained. The outputs of the segmentation models trained in this application environment are stored in folders in the specified areas. The storage process allows the models to be compared with newly developed models without having to be trained again. The following settings can be made regarding the dataset and training process in the main application environment;

a. How much of the data will be used for the training process
b. How much of the data will be used for the test process
c. Number of Epochs
d. Patience
e. Validation Split

The storage of the training process of each model is done under the Train Results folder as “ArchitectureName Validation Split=… Train=… Test=… Epochs=… Patience=…”. During this process, the storage of the numerical data belonging to the training results;

a. Numerical data: JsonFolder
b. Prediction results: PredFolder
c. Processed test data: TestImagesFolder
d. The processed test data masks are made in the form of: TestMasksFolder.

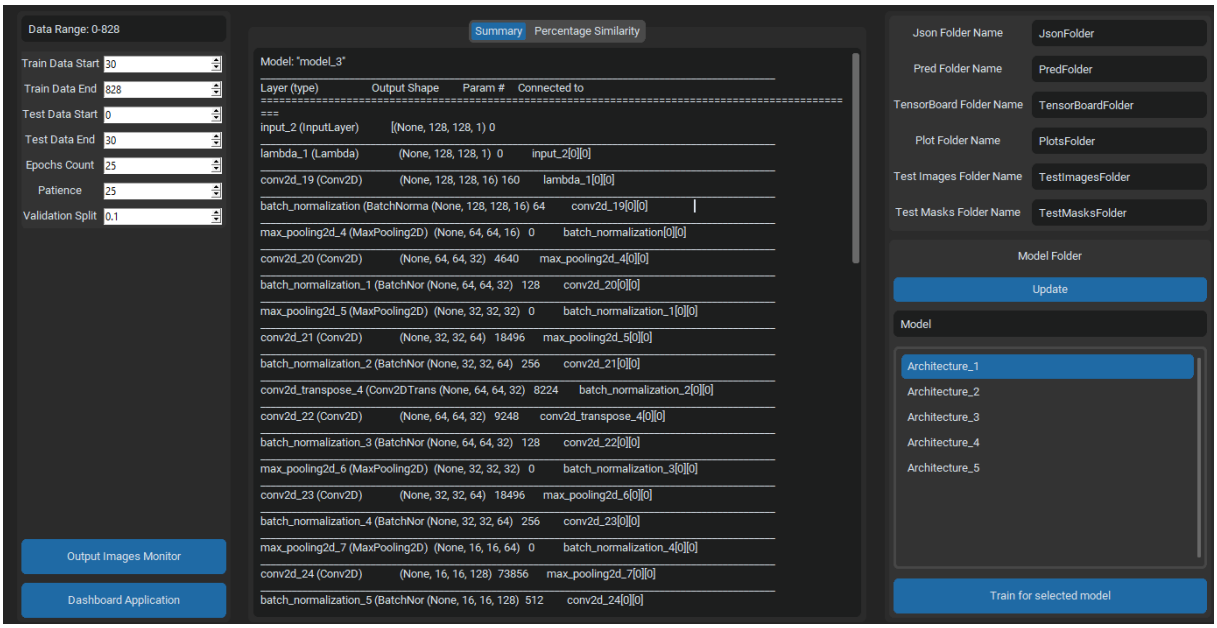


Figure 1. Main Application Interface (UserInterface)

Figure 2 shows the similarity graph of the prediction results obtained by the trained model on the test data. Thanks to this process, the similarity process on the test data can be evaluated and it will help to have an idea to eliminate the deficiencies of the model.

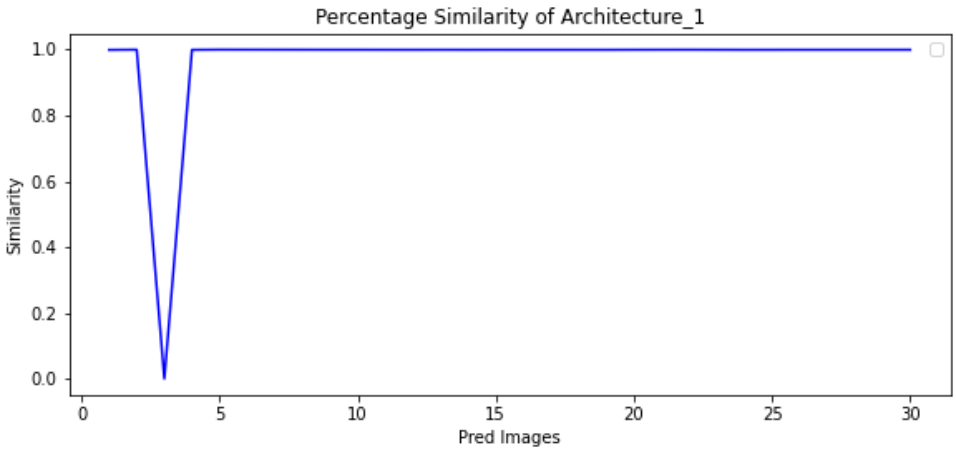


Figure 2. Similarity Values of the Predicted Data with the Real Data

Comparison of Test Data (FigureInterface)

The application environment where the similarity values of the predictions made on the test data after the training process with the original data are visualized is the FigureInterface environment.

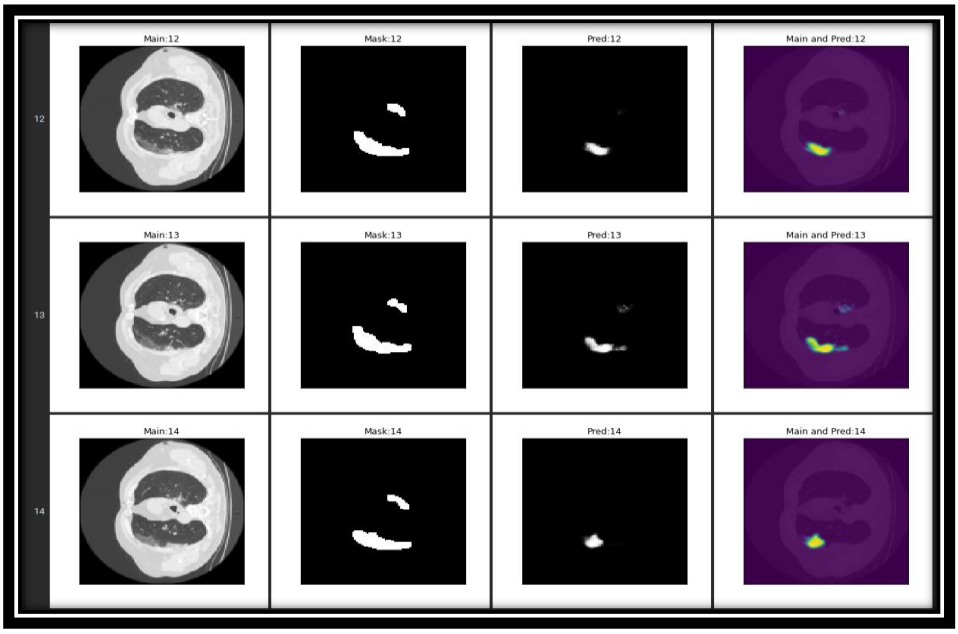


Figure 3. Listing of All Test Data and Predictions

In the FigureInterface environment, data is created by listing the real data and prediction data comparatively and displaying them individually. In Figure 3, the original lung image (Main:…), the mask of this image (the area where the disease is actually located, Mask:…), the model-predicted image (Pred:…) and the location of the predicted disease data on the lung image (Main and Pred:…) are listed. Only a part of the entire list is shown here, and all test data is included in the listing process. All prediction data here is stored in the PredFolder folder.

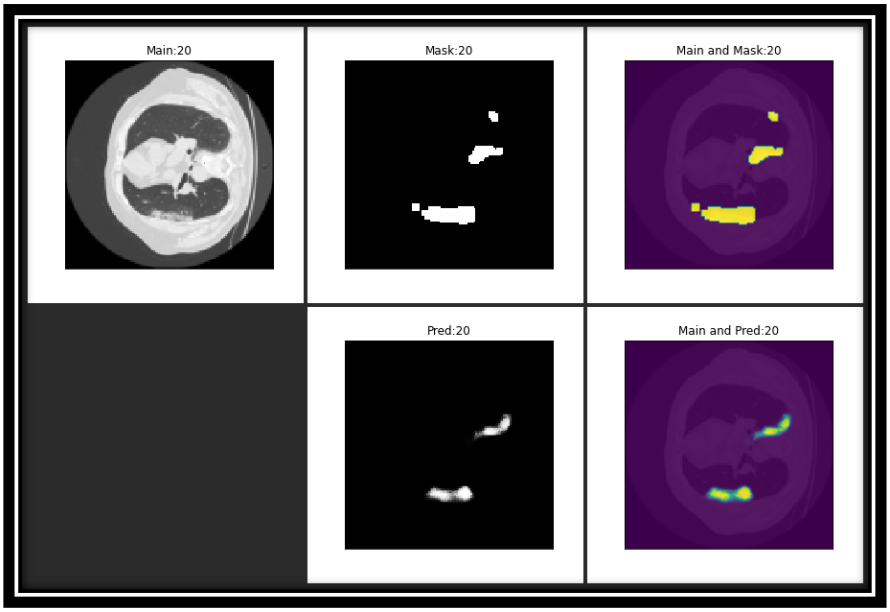


Figure 4. Prediction Data Number 20

The FigureInterface environment also includes a list for selecting the desired data. The results of the prediction data selected from the list are as shown in Figure 4. Here, the original lung image (Main: 20), the real region where the disease is located (Mask: 20), the real location of the disease on the original image (Main and Mask: 20), the prediction image (Pred: 20) and the location of the prediction image on the lung (Main and Pred: 20) are included.

Visualization of Training Outputs (DashboardInterface)

Figure 5. Dashboard Interface

The DashboardInterface in Figure 5 is the application where numerical data is visualized. This interface can be run independently or from within the main application. The “Add Json Directory” option in the application selects the folders where json training results are stored. More than one folder can be selected here, as well as a folder containing more than one json file. The selected folders will be added to the folder list at the top left. The json files in the selected folder from this list are displayed in the list below. The analysis results in the selected json file in the list containing json files are shown on the grid as shown in Figure 5.

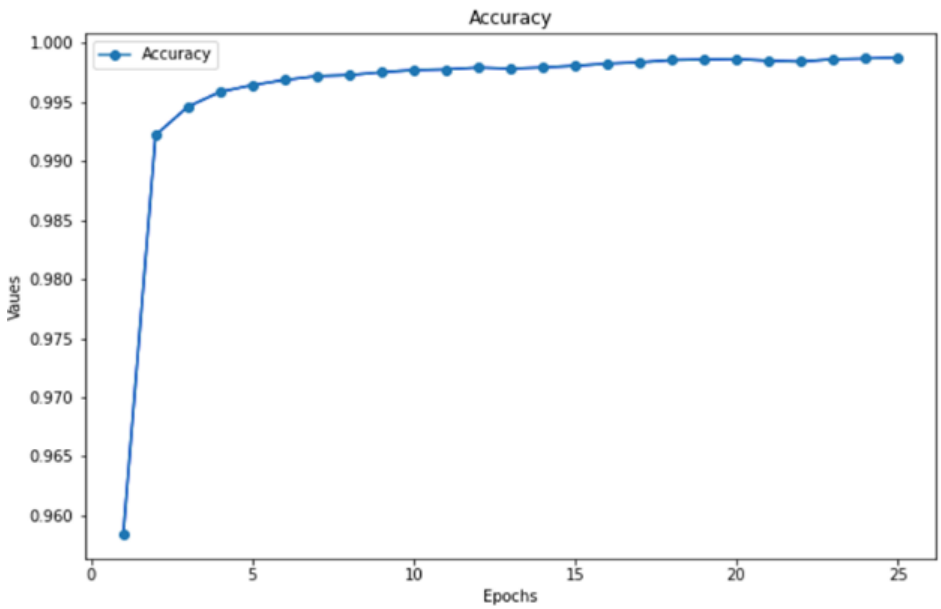


Figure 6. Sample Accuracy Graph

Figure 6 shows the graphical representation of each metric value on the grid in Figure 5 when the button is clicked. As an example, the graph created when the Accuracy field is selected is shown. The aim here is to visualize the values of the trained model on the grid and make them easier to interpret.

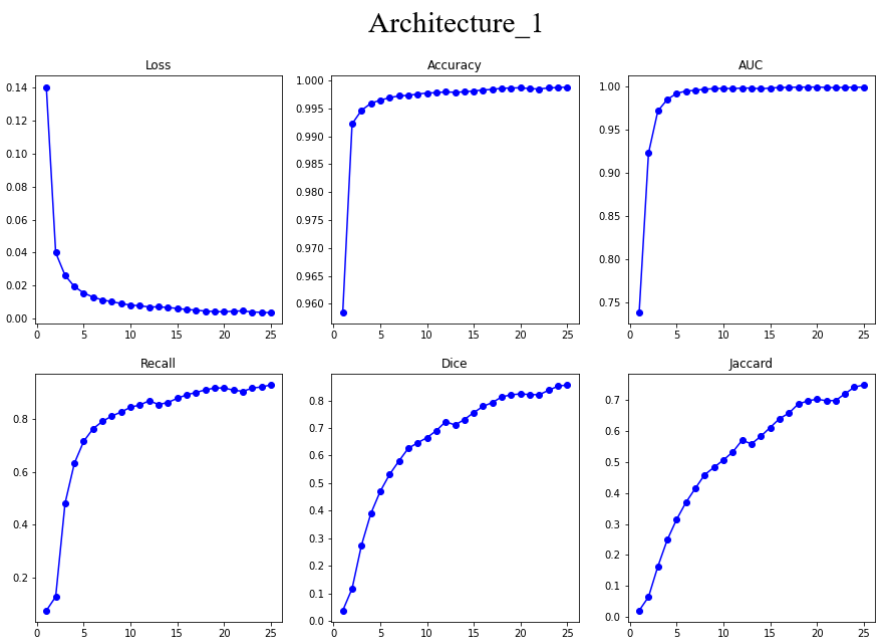


Figure 7. Loss, Accuracy, AUC, Recall, Dice and Jaccard graph

Some metric values are commonly used when training and comparing models. Reflecting the graph of these metric values as a whole facilitates analysis processes and helps to organize the areas that need attention when observing the deficiencies of the models. Figure 7 shows the graph of Loss, Accuracy, AUC, Recall, Dice and Jaccard metric values of Architecture 1 as a whole. Users can add or remove the metric values they want to this area. The selected metric values are the values commonly used in training and studies.

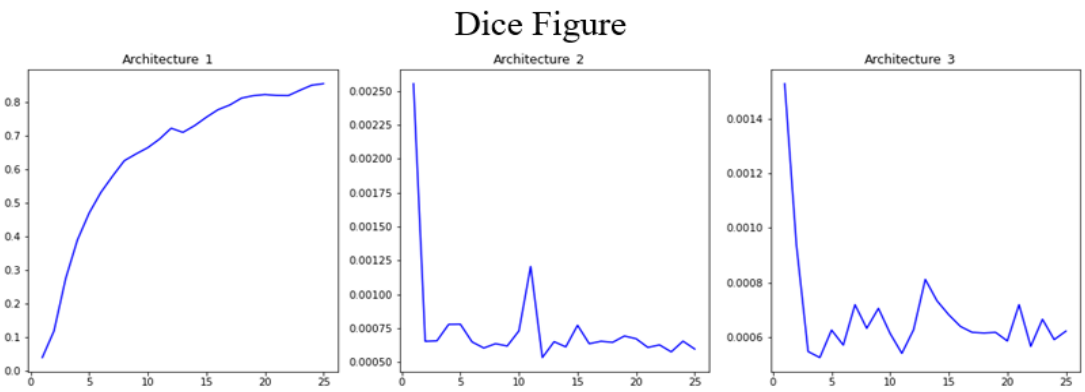


Figure 8. Comparison of Three Architectures according to Dice Value

In academic studies, the success of a model is demonstrated by proving its superiority over other models. This is provided by graphical or tabular representation. Figure 8 shows the numerical data of the trained models according to the selected metric value.

Discussion

Ronneberger et al. (2015) proposed the U-Net algorithm without a fully connected layer for segmenting microscopy images. The U-Net network and training strategy were developed to learn effectively from a small number of annotated images. U-Net takes its name from its U-shaped architectural structure as seen in Figure 9. The U-Net architecture consists of two parts. These are a contraction path to capture context and a symmetric expansion path that provides precise localization. The main feature of the architecture developed on the basic structure of the U-Net architecture is that

it does not have fully connected layers. The architecture was developed to obtain successful results on very few sample data.

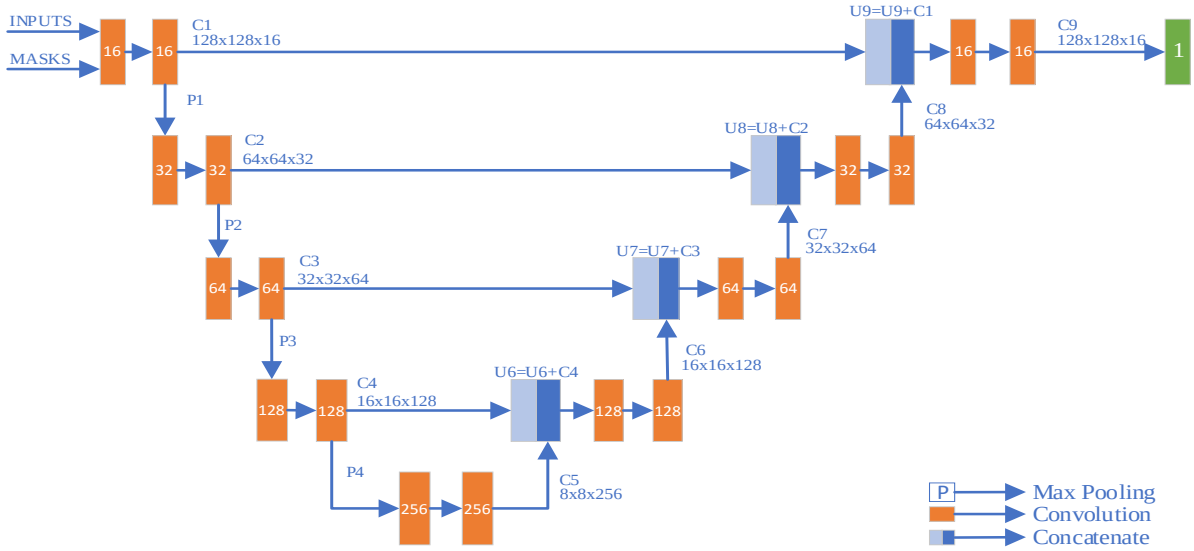


Figure 9. U-Net Architecture

Milletari et al. (2016) developed the V-Net architecture that processes using 3D MRI images. This architecture model, which was developed similar to the U-Net structure, has a contraction and expansion path. Unlike the U-Net architecture, the convolution operation increases as you go from the upper layers to the lower layers. Figure 10 shows the V-Net architecture we developed. 21 convolution operations were applied in this developed architecture.

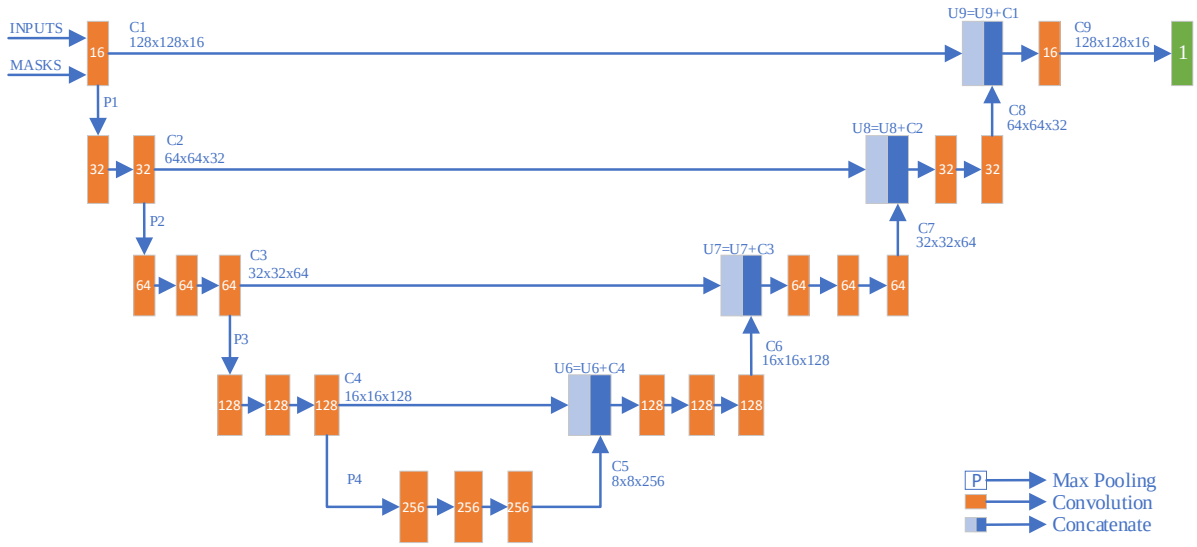


Figure 10. V-Net Architecture

U-Net and V-Net architectures are widely used architectural models in image segmentation. The 3D V-Net architecture developed by Milletari was recoded as 2D and training was performed at different Validation Split and Epochs values with the help of the developed application environment. Table 1 shows the Dice performance results of the training results obtained from the application environment on 2D Covid19 lung images of U-Net and V-Net architectures. The obtained results are the maximum results of the trainings performed on each validation split and epochs values. Table 2 shows the

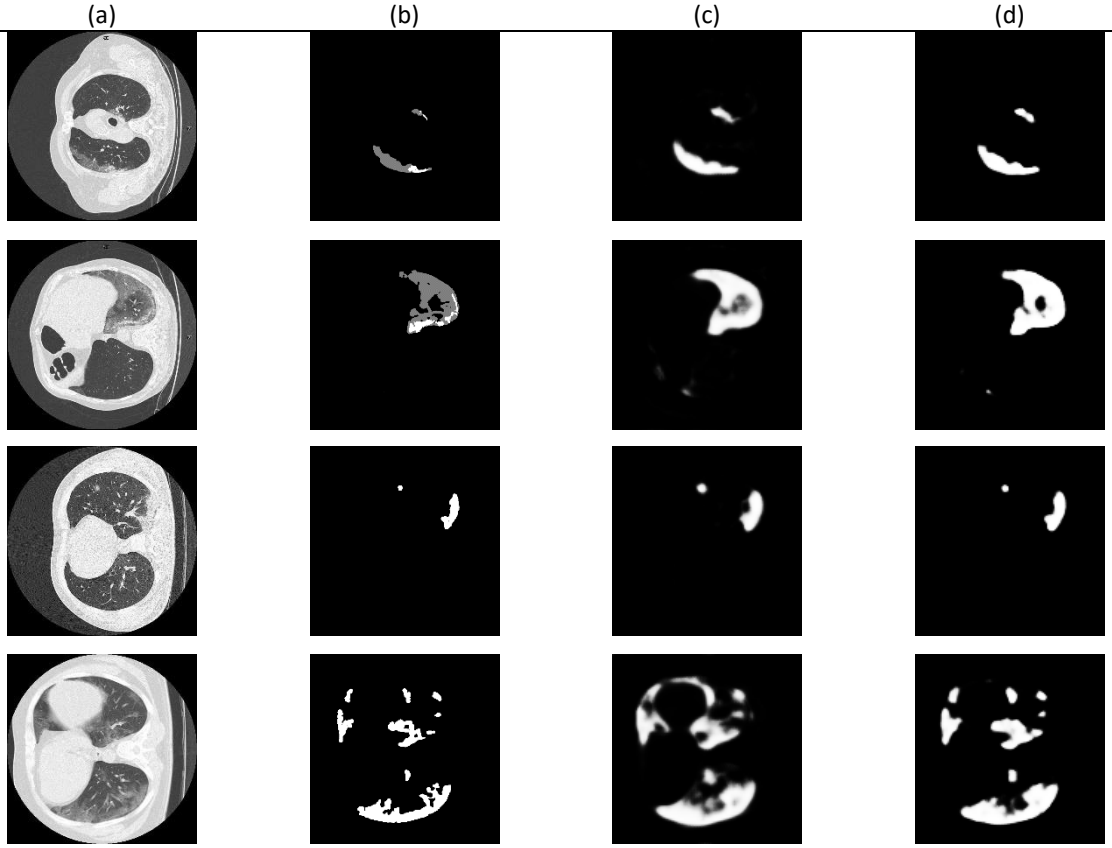
prediction results of 2D test images of U-Net and V-Net architectures. Here, (a) shows the image used for the test, (b) the ground truth value to be estimated for the original image, (c) the prediction of the U-Net architecture and (d) the prediction of the V-Net architecture.

Table 1. Dice Performance Results

Validation Split - Epochs	U-Net	V-Net
0.1 – 25	0.5175357461	0.8076153994
0.1 – 30	0.7475325465	0.8520365953
0.1 – 35	0.8093342781	0.8139239550
0.1 – 40	0.8059905767	0.8637956381
0.1 – 45	0.7994861007	0.8163979053
0.1 – 50	0.8222454786	0.8813048601
0.2 – 25	0.7607743740	0.8103617430
0.2 – 30	0.8030135632	0.8342383504
0.2 – 35	0.8165560961	0.8413328528
0.2 – 40	0.8108936548	0.8718471527
0.2 – 45	0.8210129738	0.8621217608
0.2 – 50	0.8548157811	0.8330374956
0.3 – 25	0.7804758549	0.7551715374
0.3 – 30	0.7927131057	0.8025660515
0.3 – 35	0.8165585399	0.8284928799
0.3 – 40	0.8265380859	0.8737146258
0.3 – 45	0.8172306418	0.8541257977
0.3 – 50	0.8294414878	0.9030863643

As it is seen in the scientific studies that the V-Net architecture is successful, the results obtained from the application environment support the studies.

Table 2. Prediction Results of U-Net and V-Net Architectures

Original Images		Prediction Images	
Original Images (a)	Masks (b)	U-Net Predictions (c)	V-Net Predictions (d)
			

Results and Recommendations

DeepImageSegmentationApp is aimed to be a useful application for those working in the field of deep learning-based image segmentation. Compared to existing developer environments, our application environment will facilitate the work of those working in this field. The ability to intervene in the code in the segmentation of CT images removes the limitations imposed by deep learning libraries and enables more successful work. As an example, Dice and Jaccard performance metrics have been added to the application environment thanks to the code intervention.

In order to demonstrate the success of the application environment, it has been shown that the reorganized V-Net architecture exhibits more successful results than the U-Net architecture in Covid19 detection. The V-Net architecture implemented for 3D CT images was recoded for 2D CT images and exhibited maximum results in the dice performance metric at Validation Split = 0.3 and Epochs = 50.

Although DeepImageSegmentationApp was developed for segmentation studies on 2D CT images, it can also be easily converted for segmentation of larger sized CT images such as 3D.

The application can be developed or adapted for the study performed depending on the usage and studies. Although the application was developed for the operation of deep learning-based image segmentation models, it can be easily used in other deep learning applications thanks to its simple and understandable coding. In this way, it creates a ready interface for different deep learning studies. An example of this is time series deep learning studies.

Author Contribution

Lütfü Bayrak; methodology, software, formal analysis, investigation, visualization, writing - original draft. *Kenan Koçkaya*; conceptualization, methodology, validation, writing - review & editing. *Ahmet Çınar*; conceptualization, methodology, validation, writing - review & editing. The authors wrote, read and approved the paper together.

Ethics

There are no ethical issues related to the publication of this article.

Conflict of Interest

The authors declare that there is no conflict of interest.

ORCID

Lütfü Bayrak https://orcid.org/0000-0002-2154-7270

Kenan Koçkaya https://orcid.org/0000-0002-5253-1511

Ahmet Çınar https://orcid.org/0000-0001-5528-2226

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Dynamic Analysis of a Recessed Reinforced Concrete Rectangular Water Tank under Blast-Induced Ground Motion Effect

Olgun Köksal[1], Zeki Karaca[2], Erdem Türkeli[3]

[1] Samsun University, Kavak Vocational School, Department of Construction, Samsun
[2] Ondokuz Mayıs University, Faculty of Engineering, Department of Civil Engineering, Samsun
[3] Ordu University, Technical Sciences Vocational School, Department of Construction, Ordu

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Abstract

Construction, mining, oil, forestry, and agriculture all use blasting processes both in our country and in the world. A wide range of civil engineering projects, including homes, roads, railroads, dams, and airports, use blasting technology. The blasting process provides some advantages, but it also has drawbacks. Blasting has negative impacts such air shock and ground motion. This investigation concentrated solely at ground motion induced by explosion. Utilizing the well-known MATLAB programming language, BlastGM software was implemented to obtain ground motion acceleration-time information. This software uses the maximum acceleration value and the ground motion acceleration time envelope curve to determine the acceleration-time changes of blasting-induced ground motions. Furthermore, this software uses the ground motion acceleration-time values to determine the shock's reaction spectrum. This study looked at how a recessed reinforced concrete (RC) rectangular water tank was affected by ground motion based on by blasting. In Turkey, these tanks are built very frequently. For these tanks, the impact of ground motion brought on by blasting is crucial. ANSYS software produced the recessed RC rectangular water tank's three dimensional (3D) finite element model (FEM). Furthermore, the recessed RC rectangular water tank's maximum stresses and displacements were examined. The study's findings demonstrate that the recessed RC rectangular water tank is greatly impacted by blast-induced ground motion.

Keywords: recessed RC rectangular water tank, blast-induced ground motion, finite element method, modal analysis, shock response spectrum

Patlatma Kaynaklı Yer Hareketi Etkisindeki Gömme Bir Betonarme Dikdörtgen Su Deposunun Dinamik Analizi

Öz

Patlatma işlemi, ülkemizde ve dünyada yapı, maden, petrol, tarım ve orman alanlarında kullanılmaktadır. Patlatma teknolojisi konut, karayolları, demiryolları, barajlar, havalimanları gibi çoğu inşaat mühendisliği uygulamalarında yaygın olarak uygulanmaktadır. Ancak, patlatma işleminin olumlu tarafları olmasına rağmen, olumsuz tarafları da bulunmaktadır. Patlatma, yer hareketi ve hava şoku gibi olumsuz etkiler meydana getirmektedir. Bu çalışmada, sadece patlatma kaynaklı yer hareketi incelenmiştir. Yaygın olarak kullanılan MATLAB programlama dili ile yer hareketi ivme-zaman bilgisinin elde edilmesi için, BlastGM yazılımı uygulanmıştır. Bu yazılım, yer hareketi ivmesinin zaman zarf eğrisini ve en büyük ivme değerini kullanarak patlatma kaynaklı yer hareketlerinin ivme-zaman değişimlerini elde etmektedir. Ayrıca, bu yazılım, yer hareketi ivme-zaman değerlerinden patlama şokunun tepki spektrumunu da elde etmektedir. Bu çalışmada, patlatma kaynaklı yer hareketinin gömme betonarme dikdörtgen su deposuna etkisi incelenmiştir. Bu depolar, Türkiye'de çok sık inşa edilmektedir. Bu nedenle, patlatma kaynaklı yer hareketinin etkisi bu depolar için önemlidir. Gömme betonarme dikdörtgen su deposunun üç boyutlu sonlu eleman modeli, ANSYS yazılımı ile elde edilmiştir. Bununla birlikte, gömme betonarme dikdörtgen su deposunun en büyük gerilmeleri ve yer değiştirmeleri incelenmiştir. Bu çalışmanın sonuçları, patlatma kaynaklı yer hareketinin, gömme betonarme dikdörtgen su deposunu önemli derecede etkilediğini göstermektedir.

Anahtar Kelimeler: gömme betonarme dikdörtgen su deposu, patlatma kaynaklı yer hareketi, sonlu elemanlar yöntemi, modal analiz, şok tepki spektrumu analizi

*Corresponding Author: Erdem Türkeli erdemturkeli@odu.edu.tr

Introduction

The tunneling process for major technical projects like dams, roads, railroads, and underground infrastructure now inevitably involves blasting. To get materials from quarries for those mentioned constructions as well as for all other construction purposes, blasting activity is also executed. Because of this, as technology advances, blasting is more preferred in civil engineering applications. For the majority of structures that are proposed to be built, a blasting study must be designed and carried out. Prior to blasting, the location of the blasting center and the impact on existing structures must be taken into account. It is possible to predict how blasting may impact dwelling regions' structures with early planning. As previously mentioned, blasting offers time and cost savings in the majority of civil engineering applications. However, blasting has a lot of drawbacks in addition to its advantages. Negative impacts include air shock, ground displacement, and the ejection of natural materials (rock particles, ground particles) during the blasting process. Ground motion, one of blasting's adverse impacts, was investigated in this study. Damage to a masonry structure and the ground caused by blast-induced ground motion can be seen in Figure 1 (Köksal & Karaca, 2018).

Figure 1. Damages Resulted From Blasting-Induced Ground Displacement (Köksal & Karaca, 2018)

In the technical literature, there are many studies dealing with effect of blast-induced ground motion on the structures. Wu and Hao (2005) formulated simultaneous air blast and ground shock forces that are readily applicable to structural response analysis of adjacent structures. Wu et al. (2005) analyzed the damage and 3D dynamic response of masonry and masonry-infilled RC frame structures to ground excitations caused by blasting. Lu and Wang (2006) described the structural effects of above-ground explosions, emphasizing the relative significance of global dynamic response and localized damage on the overall behavior of a structural system, as well as the role of ground vibration in the process. Özmen (2006) demonstrated the effects of blast-induced and earthquake-induced ground motions on structural systems that have two and multiple degrees of freedom and utilized the finite element method to calculate the acceleration-time changes of ground vibrations caused from different explosives. In order to establish safe ground vibration levels for residential buildings and other structures in mining zones, Singh and Roy (2010) explained the impact of blast-induced ground vibration on the potential for damage to residential structures. Hao and Zhou (2011) predicted the reaction of stiff structures to ground shock numerically and theoretically. Köksal and Karaca (2020) investigated how blast-induced ground motion affected the RC retaining walls' dynamic response. Moghadam et al. (2022) studied the explosion effect, splash waves and water surface tension on the walls of above-ground cylindrical RC water storage tanks. Raikar and Kangda (2024) intended to implement passive control techniques in the form of fluid viscous dampers in order to counteract blast-prone ground vibrations and lessen the possibility of damage to water tank structures. Alipour et al.

(2025) investigated the blast effect on hoop stresses and displacements created on the wall of over-ground RC water tanks by using ABAQUS software.

Material and Method

Blast-Induced Ground Motion Modelling

Examining blasting-induced ground motions reveals that they are exceptionally frequent and transient. The behavior of these ground motions is influenced by numerous factors. These criteria include the explosive weight, blast center depth, vertical distance between the center and the structure, and the geotechnical characteristics of the rock and ground.

Investigations into the impacts of earthquake-induced ground motion on buildings are ongoing both nationally and internationally. Either historical earthquake records or artificial earthquake records are used in these studies' dynamic analyses. Researchers additionally draw close attention to how existing structures are affected by ground movements brought on by blasting, which is widely used nowadays. Therefore, just as dynamic analysis of structures performed for earthquakes, dynamic calculations for blasting must be conducted carefully. The recessed rectangular RC water tank is located vertically R away from the blasting center in Figure 2.

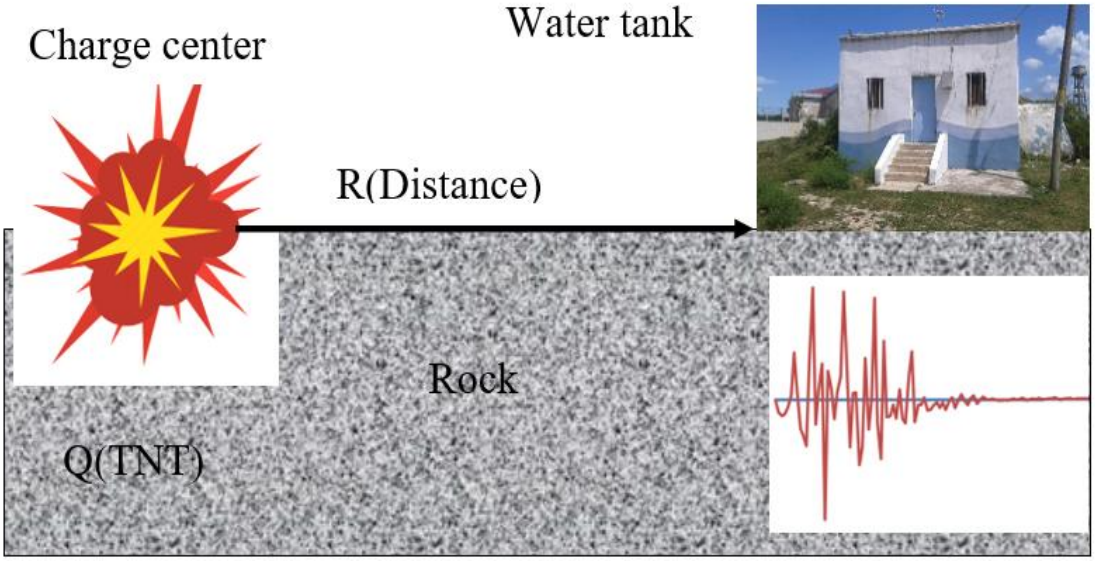

Figure 2. The RC Water Tank at a Perpendicular Distance R From The Blasting Center, The TNT Explosive, and The Blasting Center

The vertical distance to the explosion center, the peak acceleration value based on the explosive weight, and the blast pressure time envelope curve can all be used to model blast-induced ground motion (Wu & Hao, 2005). The non-stationary random process approach can be used to develop a model of ground motion caused by blasts Ruiz and Penzien (1969). To estimate ground motion acceleration values that characterize blast-induced ground motion, a software program known as BlastGM (Artificial Generation of Blast Induced Ground Motion) has been developed by Köksal (2013). The weight of the explosive and the distance perpendicular to the blast center are used to create artificial acceleration values. It is also possible to acquire velocity, displacement, and blast pressure values that vary with time.

In this study, direct effect ground motion was represented using empirical equations derived from earlier field studies. Time-dependent acceleration recordings of granite soil are produced by using Equation 1 to express direct impact ground motion Wu and Hao (2005).

$$PPA = 3.979 \cdot R^{-1.45} \cdot Q^{1.07} (g) \quad (1)$$

where PPA is the maximum particle acceleration, R is the vertical distance from the blast center (m), Q is the weight of the TNT explosive (kg), g=9.81 m/s^2 is the acceleration of gravity.

The weight of the explosive, the vertical distance from the explosion center, and the ground characteristics can all be taken into consideration when calculating the maximum accelerations of direct effect ground motions using Equation 1. Acceleration-time values that indicate ground motion are essential for the dynamic analysis of many civil engineering structures. However, for safety and economic reasons, conducting the required experimental research for blasting presents certain challenges. Therefore, it becomes necessary to create blast-induced ground motions artificially when it is needed to investigate the impact of such motions on structures. In this study, the developed software was used to artificially obtain acceleration-time values that can be considered in situations where the dynamic effects of blasting cannot always be determined experimentally.

Ground motion caused by blasts is modelled using the non-stationary random process approach. The deterministic shape function (time density envelope function) p(t) and stationary process w(t) parameters are used in this method to compute ground motion acceleration values (Ruiz & Penzien, 1969). Equation 2 was also used to express blast-induced non-stationary ground motion (Amin and Ang, 1968).

$$a_b(t) = p(t) \cdot w(t) \tag{2}$$

In earthquake engineering, the shape function is utilized to identify the non-stationary aspect of seismic ground vibration in terms of timing. The Hilbert transformation yields the shape function for Equation 2 (Kanasewich, 1981). Likewise, the envelope of blast-induced ground motions can be exponentially modelled by this shape function. Equation 3 provides an expression for this function (Wu and Hao, 2005).

$$p(t) = \begin{cases} 0 & t \leq 0 \\ mte^{-nt^2} & t > 0 \end{cases} \tag{3}$$

The non-stationary aspect of ground motion is associated with the parameters m and n. t_p determines the parameters m and n, while e is the natural logarithm. The acceleration from t_a to its highest value is measured by time t_p (Wu & Hao, 2005).

$$t_p = \sqrt{1/2n} \tag{4}$$

$$m = \sqrt{2ne} \tag{5}$$

Equation 6 can be used to quickly figure out the arrival time of the vibration wave to a place on the surface that is R from the blast center based on the conducted experiments (Wu & Hao, 2005).

$$t_a = 0.91 \cdot R^{1.03} \cdot Q^{-0.02} / c_s \tag{6}$$

The P wave velocity of granite soil is denoted by c_s. Equation 7 provides the empirical relation for the predicted time t_p (Wu and Hao, 2005).

$$t_p = 5.1 \cdot 10^{-4} \cdot Q^{0.27} \cdot (R/Q^{1/3})^{0.81} = 5.1 \cdot 10^{-4} \cdot R^{0.81} \quad \text{(s)} \tag{7}$$

It is evident that t_p solely depends on the distance R. The ground motion wave's duration is a crucial factor that influences the structural effect. The tremor wave duration in this study is defined as t_d, which is obtained using Equation 8.

$$t_d = t - t_a \tag{8}$$

A damped single-degree-of-freedom linear system, represented by the undamped angular frequency ω_0 and damping ratio ξ, is used to approximate the ground layer's filter effect. $a_g(t)$ ground motion acceleration is obtained by solving Equations 9 and 10 (Ruiz & Penzien, 1969).

$$\ddot{z} + 2 \cdot \xi \cdot \omega_0 \cdot \dot{z} + \omega_0 \cdot z = -a_b(t) \tag{9}$$

$$a_g(t) = -2 \cdot \xi \cdot \omega_0 \cdot \dot{z} + \omega_0^2 \cdot z \tag{10}$$

Obtaining Blasting Pressure and Ground Motion with BlastGM Software

In order to create artificial ground motion and blast pressure, a software named BlastGM has been created using the MATLAB programming language (Amin & Ang, 1968; Kanasewich, 1981; Köksal, 2013;

MATLAB, 2012). By entering the explosive weight, time step, and ground type (damping ratio, seismic velocity), this software creates artificial ground motion from blasting using Equations 1–10. The software is compatible with SI and American unit systems, as well as Turkish and English languages. Figure 3 displays the information entry, and Figure 4 also displays the software's flow diagram.

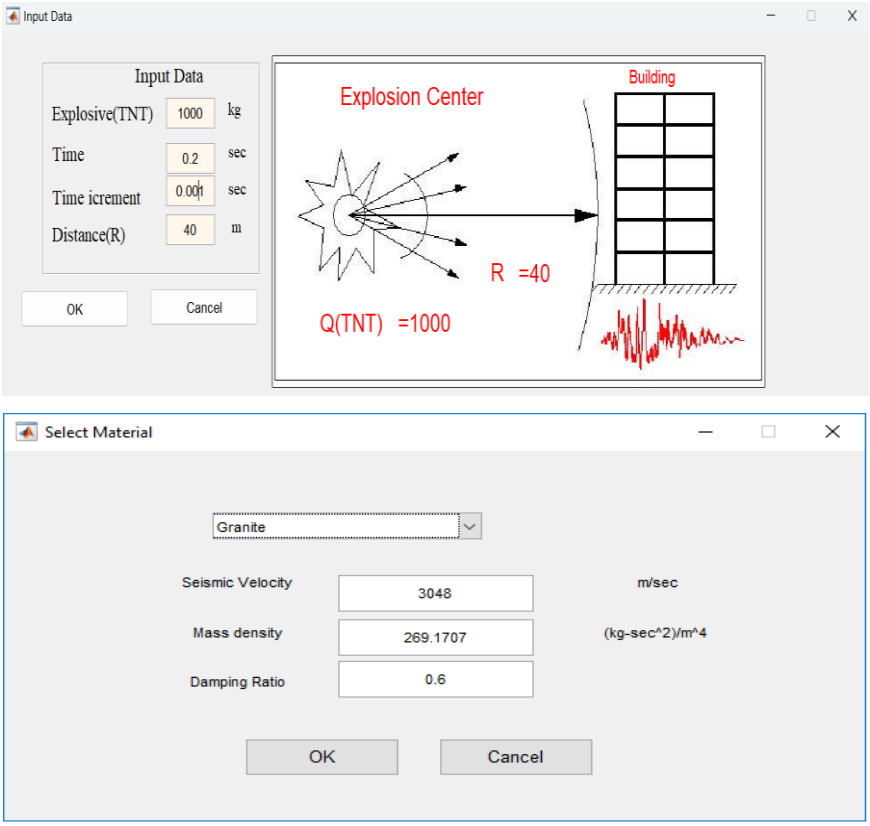

Figure 3. Screenshots of the BlastGM Software Login Details

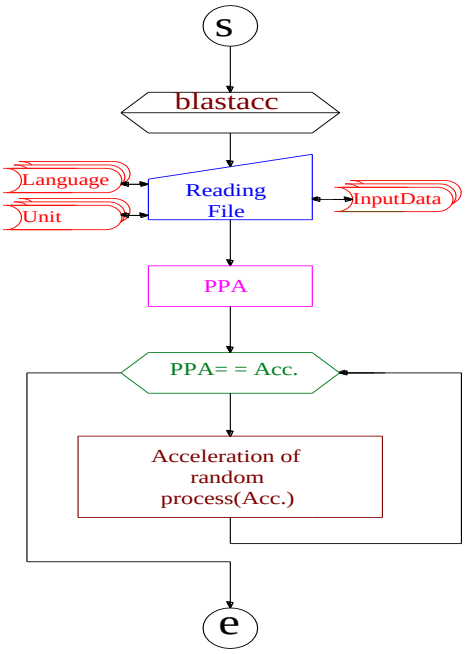

Figure 4. BlastGM Software Flow Diagram

Obtaining the Shock Response Spectrum

In the early 1960s, Shock Response Spectrum (SRS) analysis became a standard data processing technique. Assume that the base plate of a mechanical system with flexible mounting elements has numerous small tools or other components, such as substructures, attached on it. Stiffness and damping characteristics can be used to define it. The mechanical oscillator is a single-degree-of-freedom (SDOF) system that is produced by the mass of that substructure. The fundamental natural frequency and damping are the two primary parameters that show a SDOF system's free oscillation. The definition of damping is based on numerous criteria. Nonetheless, the damping ratio is usually set at a preset value as 5%. Equation 11 defines the spectrum of a damped shock response.

$$S_A = \left|\omega \int_0^t a_g(\tau) e^{-\xi\omega(t-\tau)} \sin \omega(t-\tau) d\tau\right|_{max} \tag{11}$$

SA represents both the spectral acceleration and the change in the single-degree-of-freedom system's fundamental acceleration with time (Tuma et al., 2011). Using the acceleration-time values derived from the solution of Equations 9 and 10, the response spectrum of blast-induced ground motion is determined. BlastGM software, which was created using the MATLAB program, was used to determine the acceleration-time values of blast-induced ground motion (Köksal, 2013). The Kelly-Richman technique (Kelly & Richman, 1971) was used to convert these acceleration data into values for the shock response spectrum. The BlastGM software's information inputs and the generated acceleration spectrum-frequency graph are displayed in Figure 5 (Irvine, 2013).

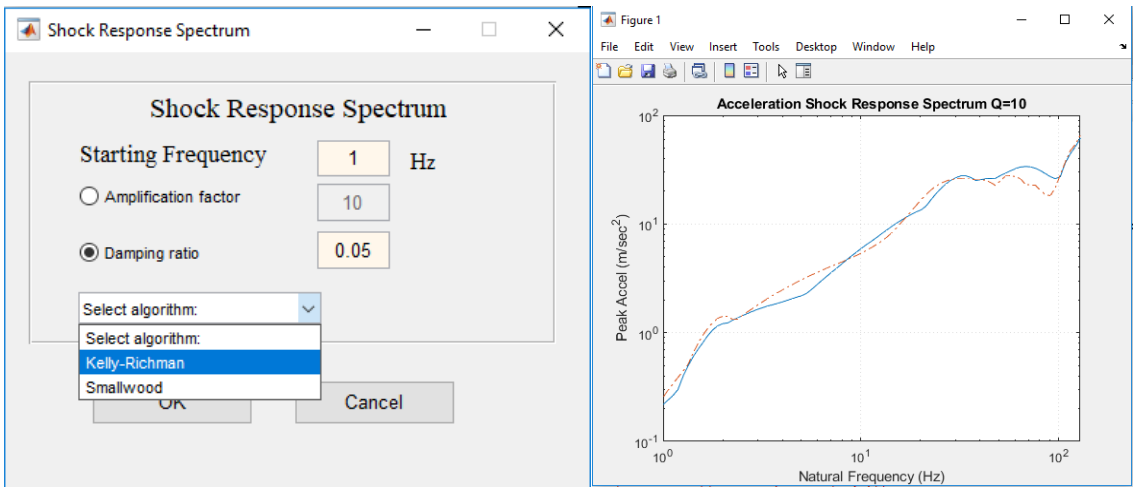

Figure 5. Login Information and Shock Spectrum Graph Screenshots in Blastgm Software

Dynamic Analysis of Recessed Reinforced Concrete Rectangular Water Tank

The primary food source for people and other living things, water, is becoming less and more contaminated as the population grows. Since the beginning of history, humans have needed to conserve water. Our source of life, water, is the first thing that those individuals demand when unfavorable events like earthquakes, floods, fires, explosions, and epidemics occur. Clean drinking water must therefore be acquired in compliance with regulations and properly kept. To deliver the required pressure in the network, recessed RC rectangular water tanks have been built at elevated locations near city centers. In Turkey, State Hydraulic Works, Provincial Banks, Special Provincial Administrations and Municipalities use the typical projects of these tanks. The dynamic analyses of a 100 m^3 recessed RC rectangular water tank with two compartments under the influence of blast-induced ground motion was considered in this study. Figure 6 displays the cited tank's cross-section, actual view and FEM.

(a) (b) (c)

Figure 6. (a) Cross-section of the Tank (b) Actual View and (c) FEM.

BlastGM software was used to acquire these three ground motions resulting from blasting, which was supposed to have taken place on stiff soil using 100 kg, 500 kg, and 1000 kg TNT explosives at a distance of 40 m. using the above cited software, distinct response spectra for these ground motions were acquired. Only the x direction's response spectra were taken into account. Additionally, using the software mentioned above, pressure variations brought on by blasting and a typical time envelope function of blasting are depicted in Figures 7a and 7b, respectively.

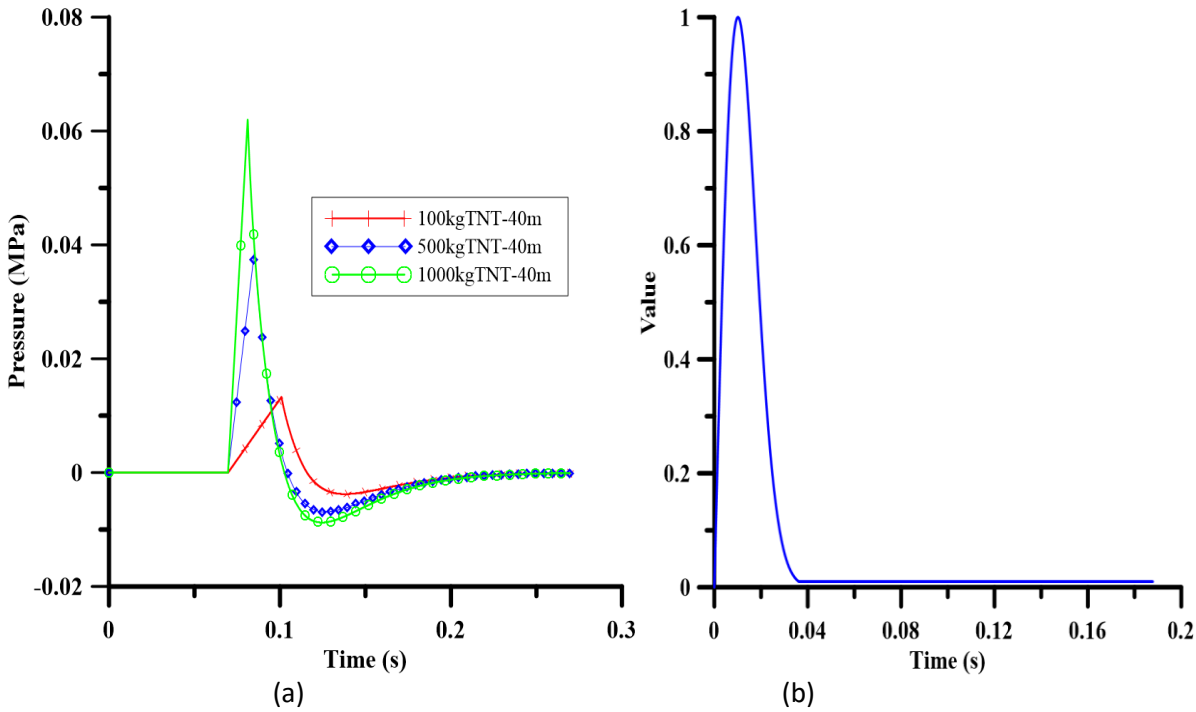

Figure 7. (a) Blasting Pressure Graph and (b) Time Envelope Function of Blast-Induced Ground Motion

Figure 8 displays the artificially produced time-dependent horizontal acceleration graph for 100, 500, and 1000 kg of TNT at a distance of 40 meters from the blast center using the BlastGM software.

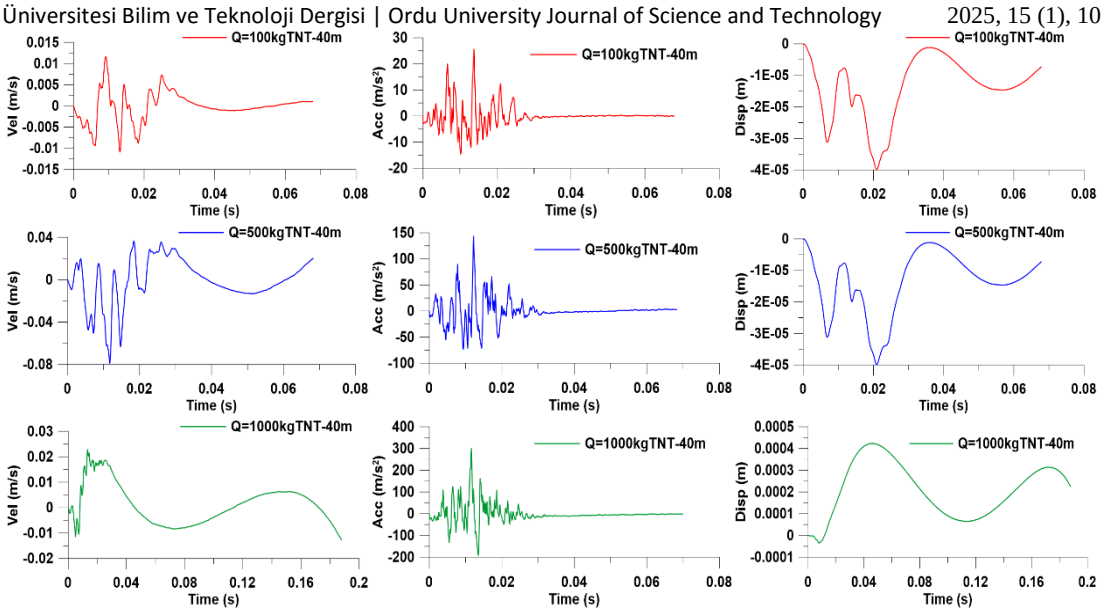

Figure 8. Horizontal Velocity-Time, Acceleration-Time and Displacement-Time Graphs Produced for 100Kg, 500Kg and 1000Kg TNT at a Distance of 40m from the Blast Center

At 40 meters from the blast center, Figure 9 displays the acceleration spectrum-frequency graph that was produced artificially using the BlastGM software for 100, 500, and 1000 kg of TNT.

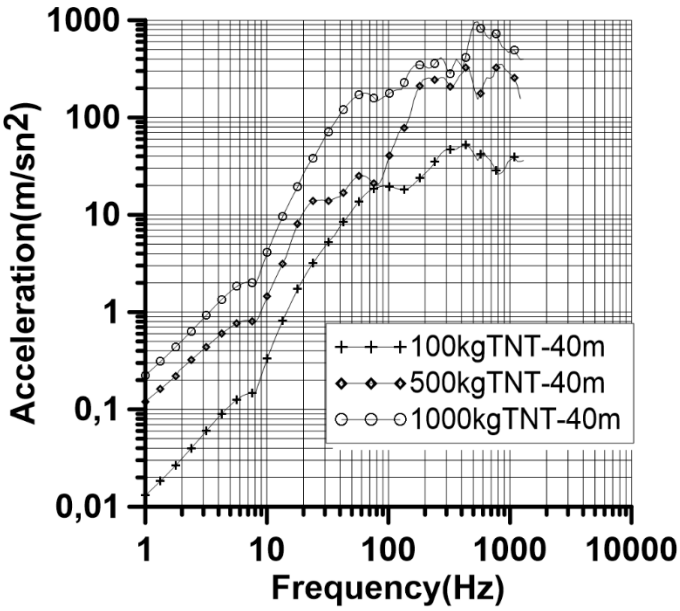

Figure 9. Acceleration Spectrum-Frequency Graphs Generated for TNT Weighing 100, 500, and 1000 Kg at a Distance of 40 Meters from the Blasting Center

The initial case involved modelling the tank using finite elements in ANSYS (ANSYS, 2024) software, fully empty and without accounting for soil thrust. Modal analysis was utilized to determine the tank's frequency ranges. The response spectrum analysis was performed with consideration for the obtained frequency ranges, and the highest horizontal displacements and stresses were analyzed. In the second scenario, the same analyses mentioned above were conducted again, but this time the tank was full of water and no soil thrust was taken into consideration. The tank's dimensions are height 3.90m, width 5.60m, and width 7.60m. The cited tank has a C25 concrete class with RC load carrying system.

ANSYS (ANSYS, 2024) software was used to model the recessed RC rectangular water tank using the finite element approach, as seen in Figure 6c. SOLID finite elements were used to simulate RC walls, floors, and foundations in the ANSYS (ANSYS, 2024) program, FLUID finite elements were used to describe water, and CONTACT elements were used to model structure-fluid interaction. It is expected that the stated tank has a built-in support that connects it to the stiff soil, which is considered to be homogeneous. The behavior of 3D SOLID elements was quadratic displacement. At every node, these elements possess three degrees of freedom. There are 45148 nodes and 5798 solid finite elements in the FEM, with a 200 mm solid element mesh selected. Table 1 provides information on the characteristics of the materials utilized in the analysis. It is assumed that the bulk modulus of water is 2.07 GPa and its density is 1000 kg/m^3.

Table 1. Material Properties

Material	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (kg/m^3)
Reinforced Concrete	30	0.2	2400

ANSYS software was used for performing modal analysis of the cited tank in the empty state. The modal analysis revealed that the shapes of the 1st, 2nd and 3rd modes were in agreement with the literature (Köksal and Karaca, 2018; Köksal et al., 2023). The outcomes are displayed in Figure 10 and Table 2.

Table 2. First Three Frequencies of the Cited Recessed RC Rectangular Tank

Mode	Frequency (Hz)
1	57.917
2	63.366
3	69.424

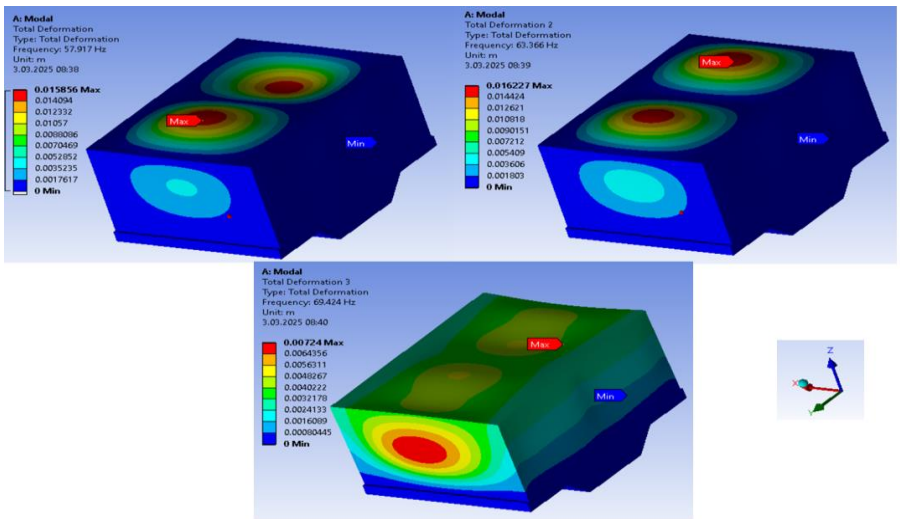

Figure 10. (a) 1st Mode Shape of the Empty Tank - f_1 = 57.917Hz, (b) 2nd Mode Shape - f_2 = 63.366Hz and (c) 3rd Mode Shape - f_3 = 69.424Hz

Response spectrum analyses were performed for ground motion at R = 40m using Q = 100kg, 500kg, and 1000kg TNT explosives following the modal analysis previously described. The findings from these analyses based on the tank's empty and full states are displayed in Figures 11-12 and 13-14, respectively.

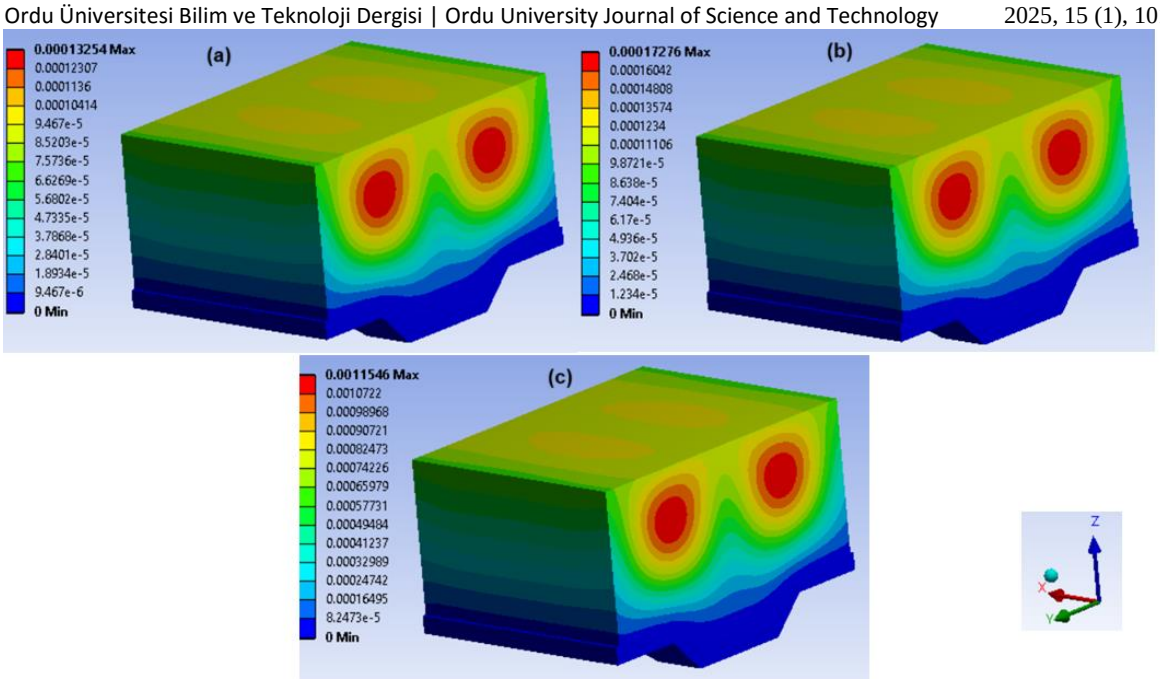

Figure 11. Displacements (m) in x Direction for R=40m in Empty Condition (a) Q=100kg TNT (b) Q=500kg TNT and (c) Q=1000kg TNT

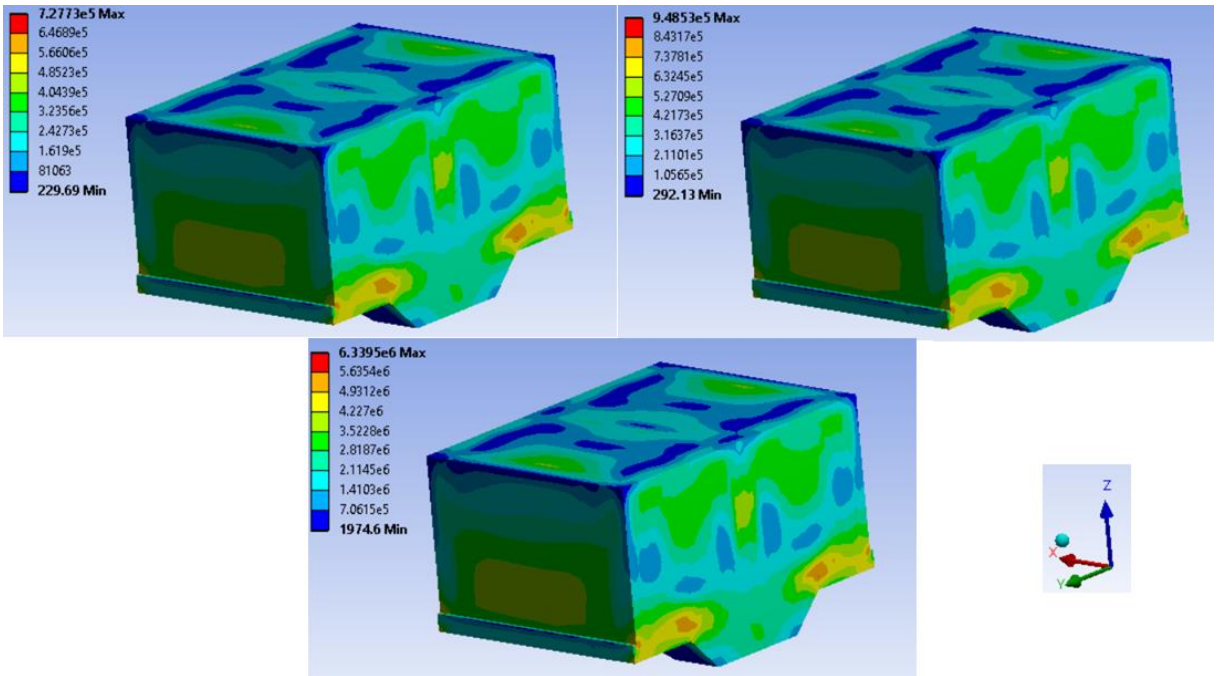

Figure 12. Von Mises Stresses (Pa) for R=40m in Empty Condition (a) Q=100kg TNT (b) Q=500kg TNT and (c) Q=1000kg TNT

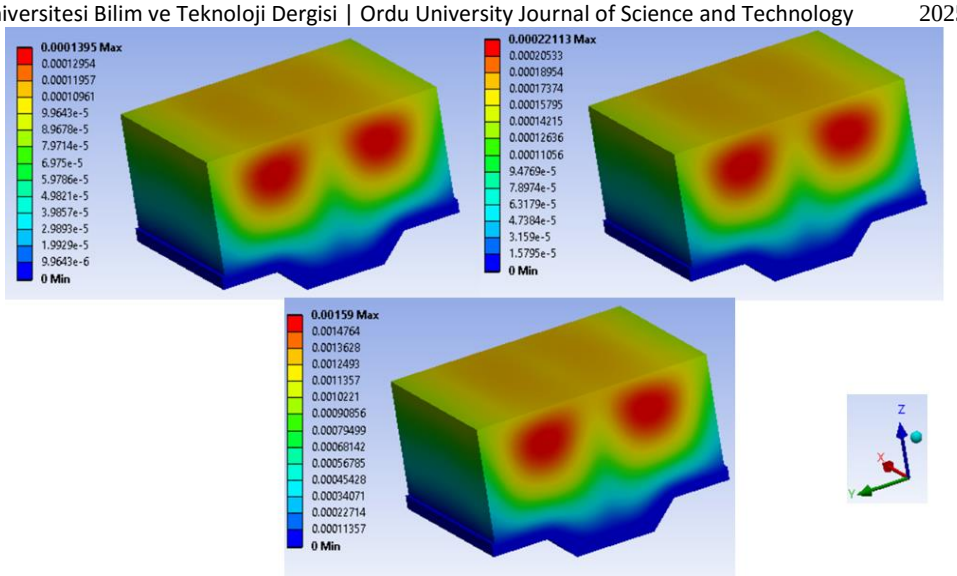

Figure 13. Displacements (m) in x Direction for R=40m in Full Condition (a) Q=100kg TNT (b) Q=500kg TNT and (c) Q=1000kg TNT

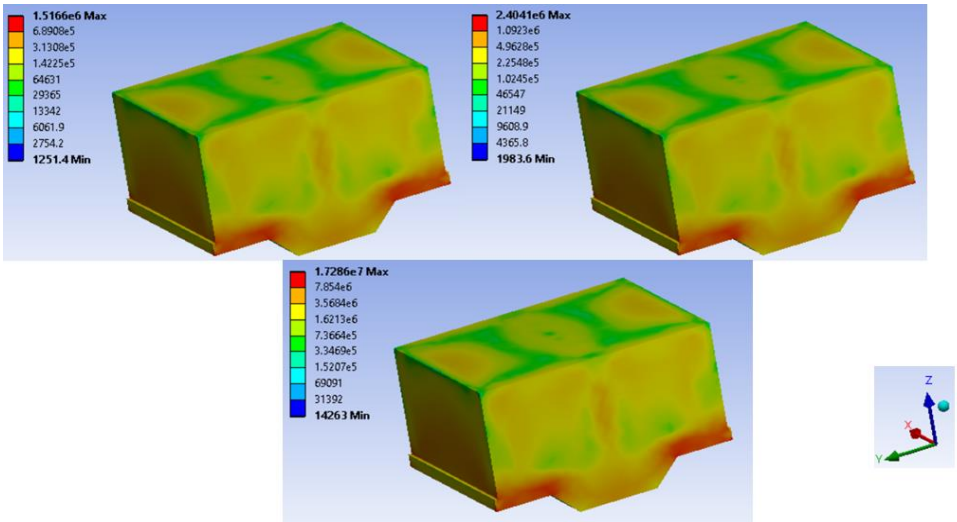

Figure 14. Von Mises Stresses (Pa) for R=40m in Empty Condition (a) Q=100kg TNT (b) Q=500kg TNT and (c) Q=1000kg TNT

Findings and Discussion

The blast induced ground motion effect on the recessed RC rectangular water tank model was analyzed with a total of six analyses with 100kg, 500kg and 1000kg TNT explosives at a distance of 40m for empty and full cases. As the analyses' results are analyzed, it is seen that when the tank is empty, the maximum displacement for Q=100kg, 500kg and 1000kg TNT are 0.00013254m, 0.00017276m and 0.0011546m, respectively. The maximum displacement for the full case at Q=100kg, 500kg and 1000kg TNT are 0.0001395m, 0.00022113m and 0.00159m. It can be clearly seen that for all weights of TNT, the maximum displacements occurred in full case are greater than the ones occurred in empty case. Also, for the empty and full cases considered, the von Mises stresses caused by the blast-induced ground motion with explosive weights of 100kg, 500kg and 1000kg were obtained. It is clearly seen from the Figures 12 and 14 that these stresses are obtained from the top of the foundation. For empty case, the maximum Von Mises stresses for 100kg, 500kg and 1000kg TNT are 0.73MPa, 0.95MPa and 6.3MPa, respectively. Moreover, for the full case considered, the maximum Von Mises stresses for 100kg, 500kg and 1000kg TNT are 1.52MPa, 2.40MPa and 17.28MPa, respectively. It can be clearly deducted from the results of the von Mises stress analyses that the maximum stress values obtained for the full case are approximately two times of the values obtained for the empty case.

Conclusions and Recommendations

In this study, dynamic structural analysis of a recessed RC rectangular water tank under the blast-induced ground motion (at 100kg, 500kg and 1000kg TNT weights) was performed for empty and full cases. The following conclusions can be drawn from the study.

Blasting on or close to the earth's surface releases an extensive amount of energy during the process that creates both direct-induced and air shock-induced ground motion. This study addresses ground motion caused by direct-induced ground motion caused by blasting. This ground motion is represented by utilizing Non-stationary Random Process method. Stiff soil experiments were used for investigating artificial ground motions. The BlastGM program was used to determine the blast's acceleration spectrum values with the help of the peak accelerations obtained during the experimental investigations. ANSYS software was used to model the cited tank using the Finite Element Method. Then, modal analysis and the related response spectrum analysis of the cited RC tank for different weights of TNT were performed. As a result of these dynamic analyses, it was determined that the maximum displacements of the full case of the cited tank increased by 5.25% for Q=100kg, 27.99% for Q=500kg and 37.71% for Q=1000kg compared to the empty case. Similarly, von Mises stresses of the full case increased by 108.22% for Q=100kg, 152.63% for Q=500kg and 174.28% for Q=1000kg compared to the empty case.

Moreover, the amount of explosive affected the maximum displacements and von Mises stresses. For the empty case, it can be clearly seen that the maximum displacements increase by 30.34% as the amount of explosive increases by 5 times and 771.13% as the amount of explosive increases by 10 times. Similarly, for the full case, the displacements increases by 58.52% as the amount of explosive increases by 5 times and 1030.79% as the amount of explosive increases by 10 times. The von Mises stresses for the empty case increase by 30.14% as the amount of explosive increases by 5 times and 763.01% as the amount of explosive increases by 10 times. In full case, the von Mises stresses increase by 57.89% as the amount of explosive increases by 5 times and 1036.84% as the amount of explosive increases by 10 times.

It can be deducted from the above findings when blasting processes are carried out close to water tanks, the case that the tank is full has the maximum displacements and von Mises stresses. Therefore, in addition to earthquakes, blast-induced effects on water tanks should be considered in the design phase in order to prevent local or fatal damages when displacements and stresses exceed the limit values. The findings in this study belong to one specific RC rectangular water tank under specified TNT weights. In order to generalize the results, different tanks should be analyzed under different amount of TNT weights.

Author Contributions

All authors have the same contribution in preparing this article. All authors have read and approved this article.

Ethic

There is no any ethical issue in publishing this article.

Conflicts of Interest

The authors declare no conflicts of interest.

ORCID

Olgun Köksal https://orcid.org/0000-0001-8448-6404

Zeki Karaca https://orcid.org/0000-0003-1130-5259

Erdem Türkeli https://orcid.org/0000-0002-4293-4712

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IMU Sensor Based Expandable Fall Detection System Design

Ahmet Turan[1], Duaa Warille[1]

[1] Samsun University, Faculty of Engineering, Department of Biomedical Engineering, Samsun

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Abstract

Falls and their consequences pose significant health problems affecting individuals of various age groups. Aging individuals are generally weaker, less stable, and slower to react, increasing the likelihood of falls and injuries. Falls are a serious concern, have a significant impact on mobility and quality of life. They also have a significant financial impact on healthcare systems worldwide. The effects of a fall can range from minor bruises, injuries, life-threatening fractures, and even fatal conditions. For these reasons, continuous monitoring of the activities of elderly and disabled people has become one of the main goals of telemedicine, and wearable devices have become widespread. The main goal of this study is to develop a system that allows for precise and automatic detection and monitoring of falls. This approach will generate timely alerts and notifications to quickly inform caregivers or medical doctors. The system created in the study is expandable and can add a large number of sensors. The data transferred from the IMU sensors placed on the patient to the Raspberry Pi is evaluated by software. A fall perception is created when sudden changes occur from the values determined as normal posture levels. Bending and falling are separated. Taking this into account, various falling variations are detected.

Keywords: elderly people, fall detection, remote patient monitoring, IMU sensor, Raspberry Pi

IMU Sensör Tabanlı Genişletilebilir Düşme Tespit Sistemi Tasarımı

Öz

Düşmeler ve sonuçları, çeşitli yaş gruplarındaki bireyleri etkileyen önemli sağlık sorunlarını ortaya çıkartır. Yaşlanan bireyler genellikle daha güçsüz, daha dengesizdir ve daha yavaş tepki verirler, bu da düşme ve yaralanma olasılıklarını artırır. Düşme ciddi bir endişe kaynağıdır, hareket ve yaşam kalitesi üzerinde önemli bir etkiye sahiptir. Ayrıca dünya çapında sağlık sistemleri üzerinde önemli bir finansal etkiye sahiptir. Bir düşmenin etkisi, küçük morluklar, yaralanmalar, hayatı zorlaştıran kırıklar ve hatta ölümcül olabilen durumlara kadar değişebilir. Bu nedenlerle yaşlı ve engelli kişilerin aktivitelerinin sürekli olarak izlenmesi tele-tıbbın temel amaçlarından biri haline gelmiş ve giyilebilir cihazlar yaygınlaşmıştır. Bu çalışmanın temel amacı, düşme durumlarının hassas ve otomatik olarak algılanmasına ve izlenmesine imkan tanıyan bir sistem geliştirmektir. Bu yaklaşım, bakıcıları veya tıp doktorlarını hızlı bir şekilde bilgilendirmek için zamanında uyarılar ve bildirimler üretecektir. Çalışmada oluşturulan sistem, geliştirilebilir özellikte olup çok sayıda sensör eklenebilmektedir. Hastanın üzerine yerleştirilen IMU sensörlerden, Raspberry Pi'ye aktarılan veriler yazılımla değerlendirilmektedir. Normal duruş seviyeleri olarak belirlenen değerlerden ani değişiklikler meydana geldiğinde düşme algısı oluşturulur. Eğilme ve düşmeler ayrıştırılır. Bu durum göz önüne alınarak çeşitli düşme varyasyonları tespit edilir.

Anahtar Kelimeler: yaşlı insanlar, düşme tespiti, uzaktan hasta izleme, IMU sensör, Raspberry Pi

Sorumlu Yazar / Corresponding Author: Ahmet Turan ahmet_turan72@hotmail.com

Introduction

Up to 30% of people over the age of 60 are at risk of falling. This can lead to injuries, worsening of pre-existing conditions, and even death (Cedeno-Moreno et al., 2024). It causes serious injuries, especially when the person who falls remains on the ground for a long time without assistance (Zurbuchen et al., 2021). Elderly and frail patients have difficulty walking and are at higher risk of falling (Ruiz-Ruiz et al., 2021). The lack of appropriate care support for elderly people living alone increases the risk of falls (Seneviratne et al., 2024; Mohan et al., 2024). In the last few years, automated systems have emerged to monitor people and improve their quality of life (Galvao et al., 2021; Seneviratne et al., 2024; Santiago et al., 2017). Such e-health technologies are of critical importance, especially for the care of elderly people living alone (Mohan et al., 2024). Early intervention for people who have fallen is important to eliminate the leading cause of death and disability in older adults. Developed warning systems reduce the costs of falls to healthcare systems (Qian et al., 2022; Nooruddin et al., 2022; Xueyi et al., 2020; Villa et al., 2024). The systems facilitate access to patient data and provide high-quality care at low costs (Malche et al., 2022). It reduces the risk of loss of life, injury, and related healthcare expenses by quickly transporting individuals who have fallen to emergency services (Gharghan et al, 2024).

Fall risk assessment and fall detection are crucial for preventing adverse and long-term health outcomes (Sophini et al., 2022). Monitoring falls to assess fall risk in daily life can provide important information to prevent future falls (Ferreira et al., 2022; Kim et al., 2022; Xiaoqun et al., 2021). It is thought that the information necessary to address the risk of falls in advance can be obtained by monitoring near-fall situations (Kim et al., 2022). In the context of sitting-to-standing transitions, sitting-to-standing transition tests are performed on subjects. Thus, non-invasive tools are developed to assess the risk of postural instability, contributing to fall prevention efforts (Lee et al., 2025). Wearable sensor systems are used to assess fall risk and detect falls, while also providing additional information on gait characteristics such as stride duration and walking speed (Ruiz-Ruiz et al., 2021; Sophini et al., 2022). Thus, it is possible to automatically identify abnormal gait (Chen et al., 2022). The large-scale dataset and benchmark algorithms created can provide valuable data and references for researchers and practitioners to develop new technologies and strategies for pre-impact fall detection and proactive injury prevention for the elderly (Xiaoqun et al., 2021).

There are differences in detection methods, system architecture, wireless communications, sensor types, performance measurements, difficulties and limitations among existing fall detection systems (Gharghan et al., 2024; Abdulmalek et al., 2022). Fall risk assessment methods performed in the scientific literature using wearable sensors are versatile (Ferreira et al., 2022). Devices consist of sensors combined with other components. These components are usually: transistors, resistors, capacitors, relays, buzzer, integrated circuits to detect falls and transmit information to emergency caregivers, and various alert mechanisms (Archibald et al., 2024). A fall detection system that monitors an older adult in real time has two main components: a wearable device and a mobile phone. When the wearable device detects a fall, the mobile phone sends an alert to emergency contacts defined by the user (Santiago et al., 2017). Fall detection systems are divided into two main categories in terms of sensor density: single-sensor and multi-sensor-based fall detection systems. While single-sensor-based systems mostly detect falls accurately, multi-sensor-based systems are more sensitive (Nooruddin et al., 2022). Combining multiple sensor signals increases the robustness of fall detection systems, while producing higher accuracy and fewer false alarms (Xueyi et al., 2020; Xefteris et al., 2021). Wearable systems have been developed by combining sensors, sensor fusion, and combining several types of sensors (Fula et al., 2024; Ruiz-Ruiz et al., 2021; Xueyi et al., 2020; Yu et al., 2021; Nahian et al., 2021).

Some systems consist of Inertial Measurement Unit (IMU) devices that provide an embedded algorithm and real-time fall detection (Fernandez-Bermejo et al., 2024). A single IMU device worn on the waist is used to obtain acceleration and angular velocity signals using accelerometer and gyroscope sensors (Kim et al., 2022). IMUs are wearable devices that are an excellent option for analyzing human

gait parameters in health monitoring applications due to their accuracy, portability, and low price. Different IMU-based methods have been developed to analyze gait parameters to assess the risk of weakness or falls (Ruiz-Ruiz et al., 2021). Commonly used IMUs can be placed at various locations on the body (waist, ankle, foot, etc.) to obtain motion data that can be better analyzed and interpreted. In addition, pressure sensor data placed under the sole of the foot is also added to the systems (Garcia et al., 2022; Sophini et al., 2022). Systems are being designed that collect data using low-energy and inconspicuous sensors attached to patients' bodies and beds, and transmit it by connecting to a smart gateway. These systems can transfer data to an electronic health record system. Thus, healthcare professionals can easily access relevant patient data (Fama et al., 2022).

The rapid development of sensor networks, the Internet of Things (IoT), machine learning (ML), and artificial intelligence techniques (AI), including deep learning (DL) models, has led to the emergence of healthcare systems that monitor patients remotely. These developments have paved the way for real-time, accurate, and rapid detection of fall accidents in elderly patients (Abdulmalek et al., 2022; Karar et al., 2022; Xefteris et al., 2021; Vimal et al., 2021; Zhang et al., 2024). The emergence of technological developments such as artificial intelligence, the Internet of Things, wearable devices, and smartphones make it possible to design fall detection systems for smart home care (Vaiyapuri et al., 2021). IoT-based systems are proposed to detect falls in elderly people indoors using low-power wireless sensing networks, big data, cloud computing, and smart devices (Kulurkar et al., 2023). To achieve high efficiency in fall detection, the data read from the sensors are processed and analyzed. If a fall is detected, an alert is generated and the system automatically responds by sending notifications to the groups responsible for the care of elderly people (Yacchirema et al., 2018). The systems also include a user interface for healthcare professionals developed based on cloud technology and server-client architecture (Qian et al., 2022). AI-IoT technology has been developed by combining the Internet of Things and Artificial Intelligence with other emerging technologies. It is envisaged that such systems will be the best solution for fall prevention in real-time and long-term monitoring without human intervention (Mohan et al., 2024). Most researchers use their own datasets to develop fall detection algorithms (Xiaoqun et al., 2021). Machine learning models are used to monitor the patient's activities such as running, sleeping, walking, and exercise, as well as vital signs such as body temperature, heart rate, and breathing patterns (Malche et al., 2022; Yu et al., 2021). Artificial intelligence techniques including machine learning and deep learning methods are used to detect elderly falls (Gharghan et al., 2024). Deep learning models combine sensors such as pressure sensors, three-axis gyroscopes, and three-axis accelerometers. Such real-time systems can classify activities performed as falls or daily living activities (Campanella et al., 2024; Galvao et al., 2021; Zurbuchen et al., 2021; Nahian et al., 2021). Artificial intelligence-based deep convolutional neural networks are used to analyze the cause of falls (Zhang et al., 2024; Vimal et al., 2021). To determine the applicability of computer vision and machine learning computation in distinguishing different gait patterns associated with falls from level ground (Chen et al., 2022).

To define a robust and reliable method, sensor fusion and multi-point measurements are required. Therefore, in order to avoid false alarms, it may be necessary to combine the analysis of signals captured by the smartwatch with signals collected by another low-power sensor placed at a point closer to the body's center of gravity (e.g., waist) (Gonzalez-Canete et al., 2021). The availability of different sensor types such as gyroscopes and accelerometers in smartwatches is a step towards realizing successful Fall Detection Systems (FDS) (Karar et al., 2022). In addition, smartwatch-based Fall Detection Systems are becoming widespread due to their widespread acceptance, ergonomics, and low cost (Gonzalez-Canete et al., 2021). In other designs, technologies that combine IMUs with Hearing Aids (HA) are being developed. Hearing aids are being transformed into hearing, headphones, and fall detection technologies with embedded sensors and artificial intelligence methods (Steenerson et al., 2025).

Night monitoring systems are being developed to provide a safe environment for the elderly and to relieve caregiver burden. Remote sensors placed in spaces are used for such systems. In addition,

pressure sensors and infrared fence systems have been designed for bed-exit scenarios (Cheung et al., 2021). Non-contact radar systems are also being created to detect elderly falls (Arnaoutoglou et al., 2024). Fall detection robots have been developed to reduce the risk of falls. The robot can detect three basic types of falls: slipping, tripping, and fainting (Seneviratne et al., 2024). Wearable device-based fall detection systems use wireless transmission methods for data transmission. Short-range technologies such as Bluetooth or network connections such as LPWAN interfaces are used (Villa et al., 2024).

One of the most important problems in fall detection systems based on wearable devices is that the fall motion is simulated under unrealistic conditions. For this reason, a large number of datasets containing acceleration samples captured during the emulation of falls and ordinary movements are obtained and artificial intelligence algorithms are trained with this data. Thus, the designed systems can distinguish real falls from daily activity movements (Silva et al., 2024, Fula et al., 2024). Human fall motions are captured with multiple cameras to create skeletal models with modeling software and human motions are created (Tang et al., 2024).

In our study, an IMU sensor-based extensible patient monitoring system was developed using Raspberry Pi-4 as a control unit. Fall detection was performed using two sensors in the prototype. By evaluating the positions of the sensors; bending, walking and falling were detected. The system was designed to communicate with a large number of sensors. The situations are directed to the specified persons via SMS.

Material and Method

In the fall detection system we designed; motion information coming from IMU sensors placed on various parts of the body is evaluated using a single Raspbery PI. I2C Multiplexer is used to select the sensors, thus creating a system that can connect 64 sensors. In the first application, two sensors are used to evaluate the operation of the system. However, while developing the system, the number of sensors will be easily increased to evaluate the patient's movements in more detail and more sensitive detections will be made by evaluating multiple sensor data. The scheme of the designed system is shown in Figure 1. The detected situation is sent to the relevant persons as a short message using an SMS service.

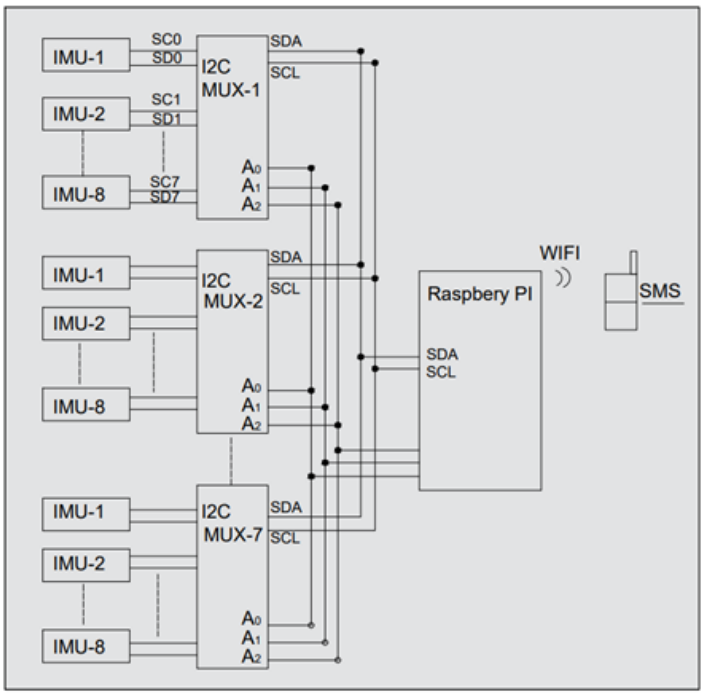

Figure 1. Schematic of the Developed Fall Detection System

Technology Used for the Designed System

Raspberry Pi: It runs a customized version of the Linux operating system. However, it also supports other operating systems such as Ubuntu, Windows 10 IoT Core, and RISC OS. Raspberry Pi supports many programming languages such as Python and Scratch as the main programming languages. There are many different operating systems and programming languages that you can run on Raspberry Pi. It is affordable, low-power, small-sized, and accessible. Raspberry Pi, shown in Figure 2, is a Single Board Computer. It can expand its capabilities with various add-on cards and accessories such as cameras, screens, and sensors. Raspberry Pi; It can be used in many areas such as simple coding exercises, home automation, web server, file server, healthcare, and automotive. Electric motor control, IP camera design, LED applications, robotic projects, device on and off projects can be done. It can turn into a computer with a keyboard, screen, and a mouse. Raspberry Pi is an ideal platform for IoT projects. Despite its small size, it is quite powerful and has a wide range of processor, memory, and storage options (Raspberry Pi OS, 2025).

Figure 2. Raspberry Pi-4 (Raspberry Pi OS, 2025)

IMU Sensor: Inertial Measurement Unit (IMU) is a sensor that combines multiple sensors including accelerometer, gyroscope and magnetometer to measure orientation, velocity and gravitational forces. IMUs are used to determine the motion and orientation of an object in 3D space. The 10DOF IMU sensor card, which includes a 3-axis gyroscope, accelerometer, magnetometer and BMP10 barometric pressure sensor, is shown in Figure 3. Using the I2C serial communication interface, all connections can be established with the microcontroller without requiring too many pins. (Inertial measurement unit (IMU), 2025).

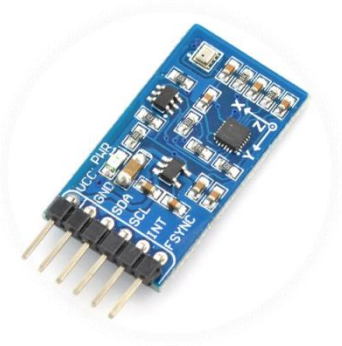

Figure 3. 10-DOF IMU (MPU-9255) Sensor Board [Inertial Measurement Unit (IMU), 2025[.

When installed inside a robot, the IMU can measure various factors such as the robot's speed, acceleration, direction, angular rate, inclination, and orientation. In the case of a magnetometer, the IMU can also measure the magnetic fields surrounding the robot. It helps with the robot's GPS positioning systems. Each component in the IMU is responsible for measuring different parameters. Accelerometer: Measures speed and acceleration. Gyroscope: Measures degrees of rotation and rate of rotation. Magnetometer: Measures magnetic fields and determines direction. Figure 4 shows the data measured by the IMU sensor.

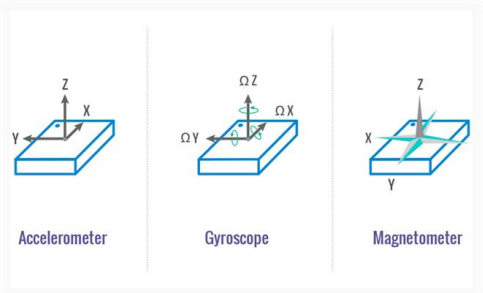

Figure 4. Measurement Parameters within the 10-DoF IMU (Robotics for Beginners, 2021).

I2C Multiplexer (TCA9548A): The I2C Multiplexer circuit board shown in Figure 5 is designed to use multiple devices (up to 8) using the same address. If there are 2 or more devices (sensors) with the same address, it will be possible to use these devices together with the multiplexer circuit. The multiplexer acts as a gatekeeper. It brings and takes commands in the I2C set selected by the applied command. The multiplexer itself comes at the I2C address (0x70) as standard. It can be placed between (0x70-0x77) to reach different MUX devices with I2C. The integrated circuit works in the (3.3V-5V) logic signal range. Dimensions: 30.6mm x 17.6mm x 2.7mm and weight: 1.8gr (TCA9548A datasheet, 2024).

Figure 5. I2C Multiplexer (TCA9548A) (TCA9548A I2C Multiplexer, 2025)

In our study, the address selection lines of the MUX (A0 A1 A2) are connected to the ground (000) and the MUX is placed at address (0x70). In order to increase the number of accessible sensor-like devices in the system, 8 separate addresses can be created between (0x70)-(0x77) with the codes (000)2-(111)2, as shown in Table 1., 8 different MUX devices can be used by changing these addresses.

Table 1. MUX Address Change

A0	A1	A2	Address
0	0	0	0x70
0	0	1	0x71
0	1	0	0x72
0	1	1	0x73
1	0	0	0x74
1	0	1	0x75
1	1	0	0x76
1	1	1	0x77

Fall Detection Method

Raspberry Pi-4 was determined as the control unit of the created system. Raspberry Pi-4 was used to detect the change data from IMU sensors and to run the software required to detect falls. IMU sensors measure movement and orientation and transmit it directly to Raspberry Pi-4. When the person wearing the wearable system moves or falls, the IMU sensor detects changes in acceleration and orientation and transmits it to Raspberry Pi-4 for analysis. This setup allowed Raspberry Pi-4 to receive real-time data from IMU sensors. Our study tested the two-sensor system.

The analysis software loaded onto the Raspberry Pi-4 was created in Python. In order to start reading sensor data, communication was established with the MPU-9255 IMU sensors via the microcomputer's I2C interface. The read sensor data (acceleration and gyroscope values) was adjusted to provide accurate measurements, thus increasing the reliability of fall detection. The created software calculates the Amplitude Vector (AM) representing the overall movement intensity using the accelerometer data. As shown in Figure 6, one of the IMUs is connected to the waist and the other to the upper leg. The system distinguishes walking, bending and falling. The number of sensors in the expandable system can be increased up to 64. Various combinations of sensor changes to be placed in different parts of the body will provide much more accurate fall detection.

Figure 6. Location of Sensors

Circuit Connection Diagram

A connection can be established with Rasppery Pi-4 via I2C. The data lines coming to each MUX input (SDO..SD7) are connected to the sensor (SDA) line by looking at the command sent. The code sent from the SCL line determines which line the data will be sent. With this selection, Rasppery Pi-4; SDA, SCL lines are connected to the SDA, SCL lines of the desired IMU sensor. The circuit connection diagram and its application on the board are shown in Figures-7 and 8. The IMU sensor is connected to the microcomputer system via "GPIO pins" (General Purpose Input/Output pins). SD0, SC0 sends a command, channel-0 becomes active (sensor-1) is read. Similarly, for SD1 and SC1; channel-1 becomes active (sensor-2) is read.

bus.write_byte(0x70, 0b00000000) → Channel 0 (Sensor 1) is activated.

bus.write_byte(0x70, 0b00000010) → Channel 1 (Sensor 2) is activated.

bus.write_byte(0x70, 0b00000111) → Channel 7 (Sensor 8) is activated.

The first part of the code sent selects the MUX address. The second part activates the channels. If new sensors were added to the system with more than one MUX, the following commands would be used.

bus.write_byte(0x71, 0b00000000) → 2.MUX, Channel-0 is activated.

bus.write_byte(0x72, 0b00000011) → 3.MUX, Channel-3 is activated.

bus.write_byte(0x77, 0b00000101) → 8.MUX, Channel-5 is activated.

Figure 7 shows the circuit connection diagram of the expandable system.

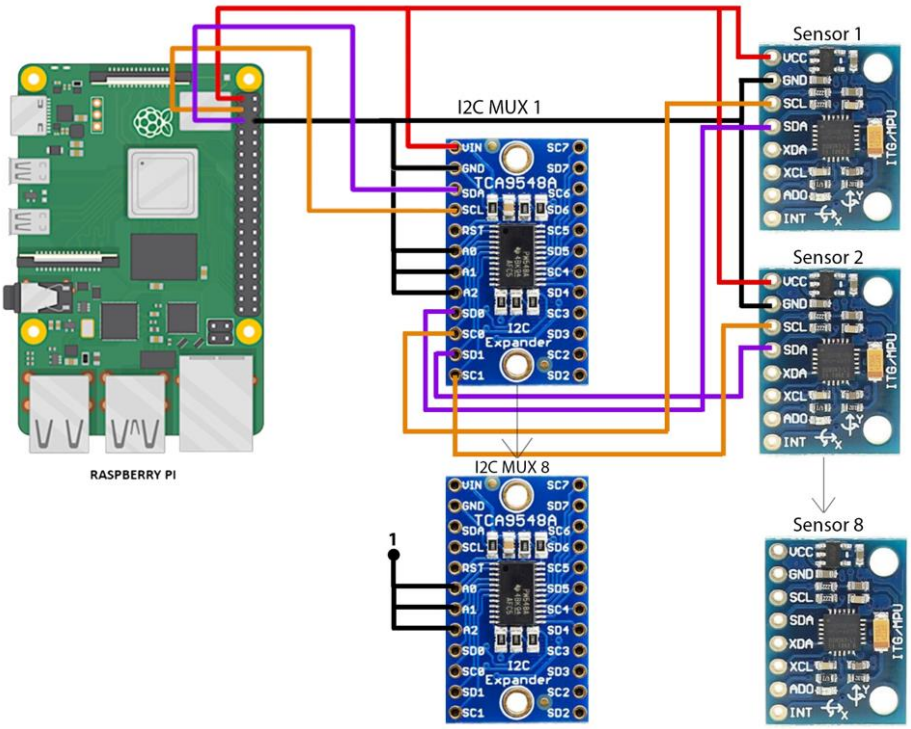

Figure 7. Circuit Connection Diagram of the Expandable Fall Detection System

Figure 8 shows the circuit connection of the two IMU sensor fall detection system.

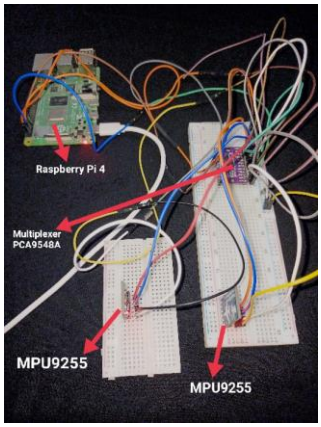

Figure 8. Circuit Connection of the Fall Detection System with Two IMU Sensors

Results

With the created software, the accelerometer and gyroscope values (x, y, z) coordinate data from IMU sensors are normalized for processing. Then, the amplitude vector is calculated for three axes. A decision is made about the patient's position according to the value ranges of the obtained result.

From the variables defined in the software;

trigger1; It is activated when the amplitude vector exceeds a lower threshold and shows a significant movement.

trigger2; It is activated when a large change in direction is detected by the gyroscope indicating a potential fall.

trigger3; If trigger2 remains active for a certain period of time, it confirms a fall indicating a continuous change in orientation. Based on the activation of trigger3, it detects a fall event indicating the characteristic change in orientation associated with falls.

When a fall is detected, the system sends an SMS to inform caregivers or take preventive measures. A message indicating the movement status is also created on the screen image during the operation of the circuit. Example fall situations and messages are shown in Figure 9. Similarly, the message generated on the computer screen for different states of the sensors and the SMS sent to the desired person are seen. As a result of falls; "falling backwards, forwards, right, left detected" message is generated.

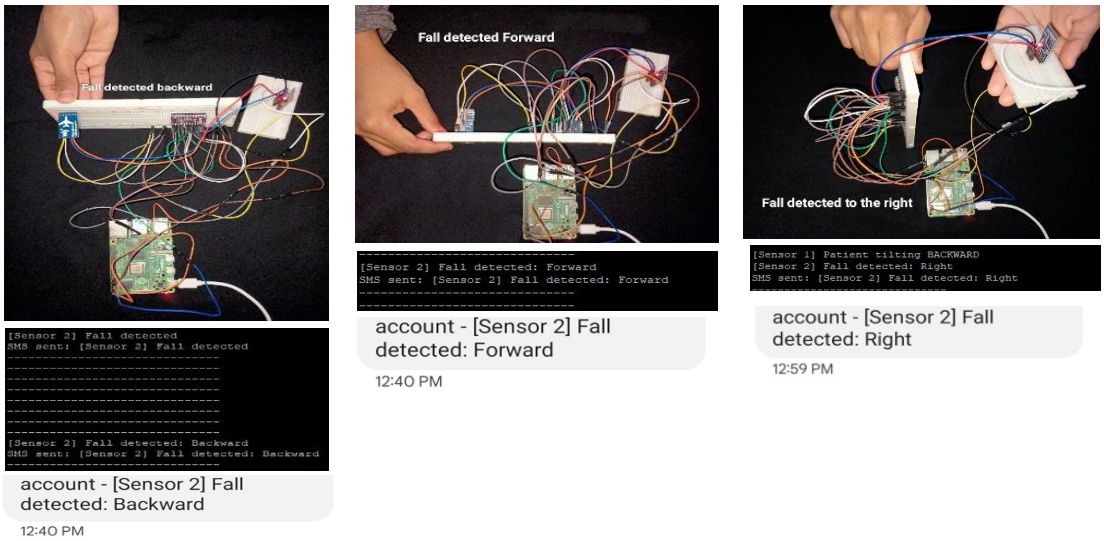

Figure 9. Examples of Situations where the "Patient has fallen" Message Occurs

Similarly, we perceive the left or right leaning from the X axis (ax) values. The situation of being below or above a certain set value constitutes this evaluation. Z axis (az): Measures the forward and backward leaning. The situation of being below or above a certain set value constitutes this evaluation. Examples for leaning situations are shown in Figure 10.

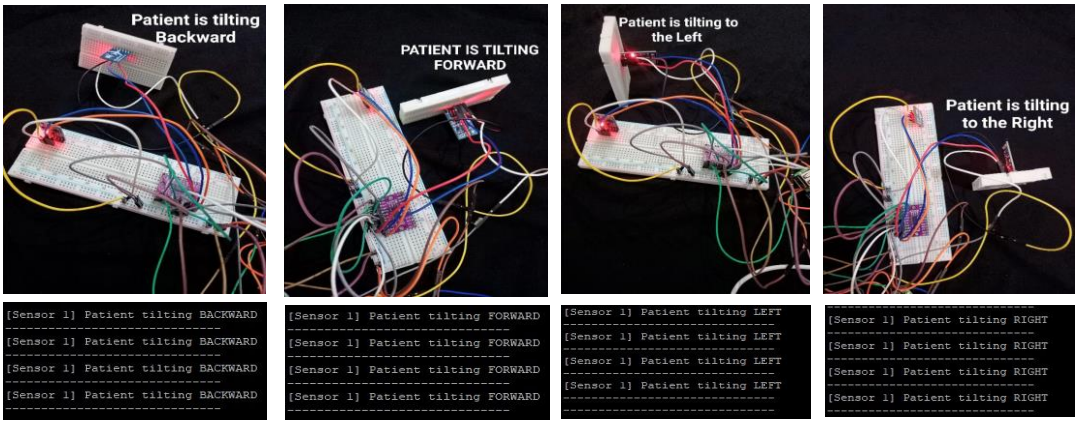

Figure 10. Bending Messages

Discussion, Conclusion and Recommendations

Many fall detection systems have been studied in the literature. Our study is an embedded system software and sensor-based study. In the study, fall and bending detection was performed with two IMU sensors. The designed system can be improved by adding many sensors. Bending and falling situations are distinguished with two sensors. The detected situation is transmitted to the relevant people via SMS. Detection accuracy will be improved by using more IMU sensors. As many sensors as

necessary will be added for the most accurate detection. A more ergonomic, easy-to-carry system will be designed. More sensitive fall detections will be made by adding more sensors to the system and associating the sensors. A panic button that can be used to warn emergency persons in case the user feels that there may be a fall will be added to the system. In addition, pressure sensors to be placed under the floor will contribute to the detection sensitivity. System accuracy should be tested with real fall situations. The portability of the developed system, when the sensors to be placed in certain places of the leg, waist, back and chest are evaluated together; walking, sitting, bending movements can be distinguished from falling actions. In addition, a pressure sensor to be placed under the sole of the foot can be integrated into the same system and the accuracy of the system can be increased. When compared to the studies in the literature, its most important difference is its flexibility. Fall detection and notification are made without being too complicated. Although the detection accuracy of the system is seen from the data received in response to the movements on the two-sensor prototype applied. This analysis will be measurable after multiple sensor connections. It is planned to add new hardware and analysis software to the developed system. The system will be developed with artificial intelligence, machine learning and internet of things support over fall models with decision support software.

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Author Contribution

Ahmet Turan and Duaa Warille determined the topic and followed the process. *Duaa Warille,* performed the data collection and statistical analysis. The authors wrote, read and approved the article together.

Ethics Statement

There are no ethical issues related to the publication of this article.

Conflict of Interest

The authors declare that they have no conflict of interest.

ORCID

Ahmet Turan https://orcid.org/0000-0001-5653-9656

Duaa Warille https://orcid.org/0009-0000-0434-3703

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When Class Time Falls Short: An Alternative Path to Application-Based Learning with GenAI

Necati Taşkın[1]

[1] Ordu University, Vocational School of Technical Sciences, Computer Technologies, Ordu

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Abstract

This study examines the impact of GenAI (Generative Artificial Intelligence) supported application-based learning on high school students' academic achievement and course perceptions in the programming languages course. The study was conducted over six weeks with 77 10th-grade students in a public high school. A quasi-experimental design was used, involving two experimental groups and one control group. While one experimental group engaged in application-based activities under teacher guidance in class, the other completed the same activities at out-of-class using ChatGPT prompts. The control group followed the standard curriculum. Quantitative data were collected using an achievement test and course evaluation scale. One-way ANOVA results indicated no statistically significant difference in academic achievement among the groups. But the mean scores of the students in the experimental groups were higher than the control group. Moreover, students in both experimental groups reported significantly more positive course perceptions compared to the control group, particularly in the dimensions of course, instructor, and method-technique. Furthermore, while a weak positive correlation was found between course perception and academic achievement, it was not statistically significant. The findings highlight that although short-term academic gains may not differ significantly, both in-class application-based activities and GenAI-supported out-of-class activities enhance students' perception of the course. The study underscores the potential of GenAI tools as pedagogical aids in promoting active learning, especially when in-class application time is limited. It suggests increasing the number of application-based course hours in the curriculum and emphasizes that, in cases where this is not possible, GenAI-supported out-of-class activities can be considered as an alternative.

Keywords: application-based learning, generative artificial intelligence (GenAI), programming education, course perception, academic achievement

Ders Zamanı Yetmediğinde: GenAI ile Uygulama Tabanlı Öğrenmeye Alternatif Bir Yol

Öz

Bu çalışmada GenAI (Üretken Yapay Zekâ) destekli öğrenmenin lise öğrencilerinin programlama dilleri dersindeki akademik başarılarına ve ders algılarına etkisi incelenmektedir. Çalışma, bir devlet lisesindeki 77 onuncu sınıf öğrencisi ile altı hafta boyunca yürütülmüştür. İki deney grubu ve bir kontrol grubunun yer aldığı yarı deneysel bir tasarım kullanılmıştır. Bir deney grubu, sınıfta öğretmen rehberliğinde uygulamalı programlama etkinliklerine katılırken, diğeri aynı etkinlikleri ChatGPT tarafından oluşturulan istemleri kullanarak sınıf dışında tamamlamıştır. Kontrol grubu standart müfredatı takip etmiştir. Nicel veriler, bir başarı testi ve ders değerlendirme ölçeği kullanılarak toplanmıştır. Tek yönlü ANOVA sonuçları, gruplar arasında akademik başarıda istatistiksel olarak anlamlı bir fark olmadığını göstermiş olsa da deney grubundaki öğrencilerin puanları daha yüksektir. Ayrıca, her iki deney grubundaki öğrenciler ders, öğretmen ve yöntem-teknik boyutlarında, kontrol grubuna kıyasla daha olumlu ders algısına sahiptir. Ders algısı ile akademik başarı arasında anlamlı olmayan zayıf bir pozitif ilişki bulunmuştur. Bulgular, kısa vadeli akademik kazanımların önemli ölçüde farklılık göstermeyebileceğini vurgulasa da hem sınıf içi etkinlilerin hem de GenAI destekli sınıf dışı etkinliklerin öğrencilerin ders algısını geliştirdiğini ortaya koymaktadır. Çalışma, özellikle sınıfta içi uygulama süresi sınırlı olduğunda, GenAI araçlarının aktif öğrenmeyi teşvik etmedeki pedagojik potansiyeline işaret etmektedir. Bu bağlamda bu çalışma uygulama tabanlı sınıf içi etkinliklerin artırılmasını ve mümkün olmadığı durumlarda GenAI destekli etkinliklerin alternatif olarak değerlendirilebileceğini vurgulamaktadır.

Anahtar Kelimeler: uygulama tabanlı öğrenme, üretken yapay zekâ (GenAI), programlama eğitimi, ders algısı, akademik başarı

Sorumlu Yazar / Corresponding Author: Necati Taşkın necatitaskin@odu.edu.tr

Introduction

As digital technologies permeate every aspect of life, it has become important for students to not only use these tools but also interact with them from a critical and creative perspective. In this context, digital literacy stands out as a multidimensional competence area that encompasses students' skills in accessing, using, producing, and sharing information through digital tools (Reichert et al., 2020). One of the fundamental components of digital literacy is software literacy. Vee (2017) demonstrates that software literacy (coding literacy) has become a universal competence area, just like reading and writing, and that this is necessary for individuals to be active in the digital world. Khoo et al. (2017) considers software literacy a basic digital citizenship requirement. Software literacy is regarded as a structure that can transform the individual's cognitive processes and modes of production. This understanding reveals an approach that encompasses not only the knowledge of programming languages but also the critical evaluation of their possibilities and limitations. Rush Hovde & Renguette (2017) state that programming languages improve students' technological literacy as well as their learning to learn, evaluation, and critical thinking competencies. In this context, the "Information Technologies and Software" course taught at a high school level aims to develop students' software literacy skills (MEB, 2023).

Within the scope of this course, ninth-grade students take the "*Introduction to Programming and Algorithms*" module, followed by modules such as "*Programming Languages*", "*Robotic Coding*", or "*Mobile Application Development*" in tenth grade. This study is based on the "*Programming Languages*" module. Providing only theoretical knowledge is not enough to develop programming skills. It is essential to provide students with application-based activities to support their learning and skill development (MEB, 2023). However, the weekly in-class course hours are limited to two. This in-class hour limitation does not provide students with sufficient practice opportunities in application-based courses such as programming languages. Programming languages education should not be limited to teaching only the basic rules of coding. It should also be structured as a learning process that allows students to understand for what purposes and how they can use this language effectively (Rush Hovde & Renguette, 2017). The fact that students receive education through application-based learning, where they interact with software, is a determining factor in their software literacy skill (Reichert et al., 2020). In this context, it is an important necessity to develop different application-based approaches and to examine the quality of these approaches. To overcome the limited in-class time for practice, one effective way is to make use of new technologies that support learning.

In programming education, students often learn best through application-based experiences. Activities such as designing simple projects like quizzes, calculators, or games using platforms like Python or Scratch help students engagingly understanding core concepts. These kinds of tasks allow them to practice writing code, spotting and fixing errors, and applying basic structures like loops and conditionals (Medeiros et al., 2019). In many classrooms, students collaborate in pairs or small groups to solve problems together, which supports both learning and motivation. Research also shows that such application-based approaches can be effectively adapted for younger learners by integrating coding into creative activities like storytelling, music, and art (Macrides et al., 2022). Among these, Generative Artificial Intelligence (GenAI) tools have become increasingly popular in programming education. When supported by GenAI tools like ChatGPT, students can take these activities further, asking questions about code, getting help when stuck, and receiving instant feedback. These interactions help make programming feel more personal and accessible, and they encourage active participation and engagement (Åkerfeldt et al., 2024).

GenAI tools can support students' learning according to their individual needs, provide real-time feedback, and make learning processes more interactive (Hsu & Ching, 2023). The personalized learning opportunities offered by these tools make learning more effective by providing guidance for students' cognitive processes, especially in application-based courses (Kadaruddin, 2023). Well-structured prompts enable students to understand complex concepts, recognize their mistakes, and access accurate information (Bozkurt & Sharma, 2023). In this context, GenAI tools can partially

compensate for the lack of application-based activities by taking on a guiding role in courses such as programming languages (Yılmaz & Yılmaz, 2023). GenAI tools like ChatGPT can act as virtual tutors, providing students with information, explaining, giving examples, and providing step-by-step guidance (Baidoo-Anu & Ansah, 2023). This feature can provide support for home-based tasks carried out outside the classroom and help students structure their learning process. Moreover, it becomes possible for students to diagnose their learning gaps and receive effective feedback (Dai et al., 2023). Thus, an environment that supports the individual development of students can be created even in learning environments devoid of teacher guidance.

Although GenAI has significant potential to improve learning and teaching processes (Bahroun et al., 2023), there are substantial shortcomings in integrating these tools into educational environments (Cooper, 2023). Lodge et al. (2023) state that there are still many questions to be resolved regarding the effects of GenAI, and the need for evidence regarding the benefits of these tools continues to grow. It is seen that studies on GenAI in education mostly focus on technical structures, and the pedagogical dimension is not taken into sufficient consideration (Dogan et al. 2023). GenAI should be embraced as here to stay (Lim et al., 2023) and integrated into all levels of education (Baidoo-Anu & Ansah, 2023). Although recent research has explored the technical capabilities and potential risks of GenAI tools in education, many of these studies primarily focus on system performance, ethical concerns, or usage patterns rather than pedagogical impact. For example, questions around bias, data privacy, and the reliability of AI-generated content are frequently addressed, yet there is limited attention to how these tools can be meaningfully integrated into teaching and learning processes (Cooper, 2023; Dogan et al., 2023; Lodge et al., 2023). In contrast, this study highlights the pedagogical value of GenAI-supported application-based learning in programming education and aims to contribute to a growing but still underdeveloped body of work focused on instructional design and student engagement. In this context, this study will not only reveal the impact of application-based learning but also provide important clues on how GenAI-supported learning can be used more functionally in educational environments.

Purpose of Research

In this study, two different methods were considered: Application-based in-class activities and GenAI-supported out-of-class activities. In this context, it is aimed to comparatively examine the effects of two different methods developed for the need for application-based learning within the scope of the "*Programming Languages*" module on students' academic achievement and course perceptions. The study sought to answer the following research questions:

1. Do different methods (application-based in-class activities and GenAI-supported out-of-class activities) significantly affect students' academic achievement scores?
2. Do different teaching methods significantly differ students' course perception scores?
3. Is there a significant relationship between students' course perception scores and academic achievement scores?

Method

This research was conducted in a high school affiliated with the Ministry of National Education in Ordu province in the 2024-2025 academic year. The study was conducted in three different classes taking the "*Programming Languages*" module of the "*Information Technologies and Software*" course in the 10th grade. The research process lasted a total of 6 weeks.

The research was designed within the quasi-experimental design, and a control group experimental design was used (Büyüköztürk et al., 2024). In this design, a control group and two different experimental groups were included, and the effects of different methods on students' academic achievement and course perceptions were examined. The groups were matched based on the scores of the students in the "*Introduction to Programming and Algorithms*" module they took in the first

term. No statistically significant difference was found between the groups in terms of grade point averages (F(2,74) =0.31, p=.734). One of the matched groups was randomly assigned to the control group, and the other two to the experimental group. Quantitative data were collected to answer the research questions within the scope of this study. The achievement test developed by the researcher was used to measure academic achievement, and the Course Evaluation Scale (CES) developed by Koç and Bulut (2022) was used to determine students' perceptions of the course.

Table 1. Research Design

Group	Matching	Treatment	Post-test
Experiment 1	M	X_1	O_1, O_2
Experiment 2	M	X_2	O_1, O_2
Control	M	X_3	O_1, O_2

X_1= application-based in-class activities, X_2= GenAI supported out-of-class activities, X_3= curriculum based standard teaching O_1= Academic achievement test, O_2=Course evaluation scale

Study Group

The study group of the research consists of a total of 77 students studying in three different classes at the 10th grade level, taking the "*Information Technologies and Software*" course's "*Programming Languages*" module in the second term of the 2024-2025 academic years. The study was carried out with the voluntary participation of the students. Before the experimental procedure, it was clearly stated to the students that the study would be conducted for scientific purposes and that the data obtained would be analyzed at the group level without including personal information. This study used convenience sampling, as the participants were selected from existing classes that were already taking the course as part of their regular school schedule. These classes were included in the study because they were readily accessible and directly related to the research, rather than being chosen at random. The distribution of students into groups is presented in Table 2.

Table 2. Demographic Information of Participants

	Male		Female		Total	
Group	n	%	n	%	n	%
Experiment 1	4	15.4	22	8.6	26	33.7
Experiment 2	7	29.2	17	70.8	24	31.2
Control	5	18.5	22	81.5	27	35.1

Research Procedure

This study was conducted within the scope of the "*Information Technologies and Software*" course (Figure 1). The courses were conducted by the same teacher in line with the curriculum plan (MEB, 2023) to ensure instructional consistency.

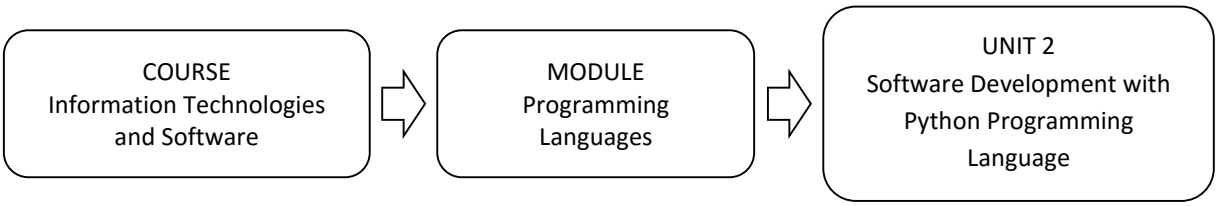

Figure 1. Link between Course, Module and Unit

In all three groups, two-hour lessons were conducted with the same content and method in line with the curriculum. The course aims to develop students' algorithmic thinking, problem-solving, and basic programming skills. In this context, students develop applications using basic programming structures such as variables, decision structures, loops, and learn to produce solutions to the problems they encounter during the coding process. The Python programming language is used within the scope of the course. One in-class lesson hour was added to the first experimental group. In

this lesson, students performed application-based activities in the classroom under the guidance of the teacher (Table 3).

Table 3. Application-Based Activities

Week	Activities	Level	Content of Activities
1	Age Calculator	Easy	input(), int(), if, print()
2	Number Sequence Processing	Easy	list, for, if, %
3	Mini Grade Evaluation System	Medium	if-elif-else, input(), int(), str()
4	Calculator App	Medium	while, def, input(), if-else
5	Number Guessing Game	Difficult	random.randint(), while, if
6	Hangman Game	Difficult	string, list, for/while, in, if, break

The second experimental group was given home-based tasks for the application-based activities that the first experimental group did in class. In these tasks, students were guided through the learning process with ChatGPT prompts. Students completed their tasks individually using prompts. This method provided the opportunity to test the potential of GenAI tools (ChatGPT) to take on a role supporting the learning process. Examples of prompts presented to students are given in Table 4.

Table 4. Number Guessing Game Prompts

Stage	Prompts	Content
Stage 1. Game Description		
Prompt 1.1	I want to generate a random number between 1 and 100. How do I do this in Python?	Random module, input () function, int () conversion.
Prompt 2.1	I want the user to enter a number. What should I do to make sure it is received as a number?	
Stage 2: Comparison		
Prompt 2.1	I want to compare the user's guess with the secret number. How do I check if it is equal, greater than or less than?	Use of if, elif, else blocks. Logical comparison operators (==, <, >).
Prompt 2.2	If the guess is large, I want it to say "*Enter a smaller number.*" How do I do that?	
Stage 3: Game Cycle		
Prompt 3.1	Let the game repeat until the user guesses correctly. Which loop and what condition should I use?	Using the while loop and loop control variables.
Prompt 3.2	When you guess correctly, exit the loop and give the message "*Congratulations!*" How do I do it?	
Stage 4: Number of Trials		
Prompt 4.1	I want to count how many times the user guessed. How do I do that?	Counter variable (counter += 1), use of variable in message (f-string, format())
Prompt 4.2	I want to show the user a message showing how many times she guessed the correct answer.	
Stage 5: Error Management		
Prompt 5.1	If the user enters letters instead of numbers, an error occurs. How can I catch this error?	Error catching (try-except).
Prompt 5.2	I want to warn the user when an incorrect entry is made. How can I do this with "*try-except*"?	Input control using, ValueError.
Stage 6: Control and Feedback		
Prompt 6.1	The full code I wrote is below. Can you find my mistakes and give me suggestions?	Code review habit, ability to receive feedback and correct.

In the control group, courses were taught in accordance with the curriculum plan and designated weekly course hours (2 hours of lessons per week). This group followed the standard instructional approach defined by the national curriculum, which primarily emphasizes theoretical explanations, textbook-based learning, and teacher-led instruction. No additional practice or application-based

activities were provided beyond the textbook examples and in-class discussions. Students repeated code written by the teacher and had limited opportunity to code independently. In this study, the effects of (1) application-based in-class activities, (2) GenAI-supported out-of-class activities, and (3) curriculum-based standard teaching process on students' academic achievement and course perceptions were comparatively examined.

Data Collection Tools

In the study, a multiple-choice test was developed to measure students' academic performance in the "*Software Development with Python Programming Language*" unit. The test consisted of 20 items, each item including one correct answer and three distractors (four options in total). Test items were aligned with the learning outcomes specified in the national curriculum and were limited to the content covered during the 6-week instructional period. The items were initially developed by the teacher and reviewed by three university experts in the fields of Information Technologies, Computer Engineering, and Educational Measurement and Evaluation. Based on expert feedback, necessary revisions were made to ensure content and construct validity. The test was piloted with a separate sample of 90 students who received the same training the previous year. As a result of item analysis, the test demonstrated acceptable psychometric properties. The KR-20 reliability coefficient was calculated as 0.77, indicating acceptable internal consistency (Başol, 2019). The mean item difficulty was 0.72, showing that most items were moderately easy, and the standard error was 1.86. The test means score was 18.11 with a standard deviation of 3.93. These findings support the reliability and validity of the test for use in the current study. The final version aimed to evaluate students' programming knowledge, algorithmic thinking, problem-solving skills, and their ability to understand and apply coding constructs such as variables, loops, and conditional statements. Sample items for the test are given in Table 5.

Table 5. Sample Test Items

Item	Bloom's Taxonomy of Cognitive Domains	Content	Explanation
What value will be printed to the screen when the following Python code is run? x = 7 y = x + 3 print (y * 2) A) 10 B) 14 C) 20 D) 24	Understanding	Defining variables and performing operations	The student is expected to understand the operations in the given code block and find the result by understanding the values of the variables.

When the following Python code block is run, what will be displayed on the screen if the user enters 13?
age = int (input ("Enter your age: "))
if age >= 18:
  print ("You are an adult.")
else:
  print ("You are not an adult.")
A) You are an adult.
B) You are not an adult.
C) Gives an error.
D) It doesn't write anything on the screen.
	Applying	Use of decision Structure (if-else)	The student is expected to make input-output connections using a decision structure and analyze the operation of this structure on a real scenario.

The Course Evaluation Scale (CES) developed by Koç and Bulut (2022) was used to determine the students' perception levels towards the course. The scale has a 5-point Likert-type scale. The scale consists of 24 items and 4 sub-factors. Course (10 items), Instructor (7 items), Method-Technique (4 items), Exam (3 items). The minimum score that can be obtained from the scale is 24, and the maximum score is 120. High scores obtained from the scale indicate that students perceive the quality of the course positively. The overall Cronbach's Alpha coefficient of the scale is 0.94, and these coefficients for the sub-factors are reported as 0.93 (course), 0.91 (instructor), 0.86 (method-technique), 0.93 (assessment and evaluation). The factor structure of the scale explains 69.3% of the total variance, and the factor loadings vary between 0.47 and 0.98. The values obtained from the fit indices show that the model has a good level of fit (X^2/df = 1.98, RMSEA = 0.063, NFI = 0.90, GFI = 0.86, CFI = 0.94, IFI = 0.98, TLI = 0.94). The fact that the item-total correlations are in the range of 0.49–0.90 indicates that the scale is strong in terms of internal consistency and discrimination (Koç & Bulut, 2022).

Data Analysis

Statistical calculations were made on the data collected within the scope of the research using quantitative data analysis methods in line with the research questions. In the analysis of the data, firstly, the assumptions of normality and variance homogeneity were tested, and parametric tests were used (Büyüköztürk, 2024).

One-way ANOVA was applied to determine the effects of different teaching methods on both students' academic achievements and perception scores of the course. The Scheffe test was used when variance homogeneity was provided, and the Games-Howell multiple comparison test was used when variance homogeneity was not provided to determine which groups had significant differences between the groups. This analysis was carried out in the context of perceptions regarding the sub-factors of the scale (course, instructor, method-technique, assessment and evaluation). Pearson Correlation Coefficient was used to examine the relationship between students' course perception scores and academic achievement scores.

Findings

Findings Regarding Students' Academic Achievements

Descriptive statistics for achievement test score of students taking courses with three different methods: Application-based in-class activities (Experiment 1), GenAI supported out-of-class activities (Experiment 2), and curriculum based standard teaching (Control) are given in Table 6.

Table 6. Descriptive Statistics for Academic Achievement Test Scores

Group	N	M	SD	Skewness	Kurtosis
Experiment 1	26	80.19	12.23	-0,33	-0,31
Experiment 2	27	79.63	8.39	-0,96	0,92
Control	24	75.42	12.41	-1,08	1,13

While the academic achievement mean score of the students in the Experiment 1 and Experiment 2 groups was found to be quite close to each other (80.19 and 79.63), the mean score of the students in the control group was determined to be lower (75.42). The results of the ANOVA test conducted to determine whether this difference was statistically significant are presented in Table 7.

Table 7. ANOVA Results of Academic Achievement Test Scores

Variance Source	Sum of Squares (SS)	Degrees of Freedom (df)	Mean of Squares (MS)	F	p
Between Groups	337.079	2	168.539	1.203	0.306
Within Groups	10366.168	74	140.083		
Total	10703.247	76			

The distribution of the variables was examined based on skewness and kurtosis, and the results (see Table 6) indicated that the data were within acceptable limits (±1,5) for normality (Tabachnick & Fidell, 2019). According to the results of the Levene test performed before the analysis, it was determined that the variances were homogeneous (Levene Statistic = 0.631; p = 0.535). As a result of the one-way ANOVA analysis, no statistically significant difference was found between the groups in terms of academic achievement scores of students (F(2,74) = 1.203, p = 0.306).

Findings Regarding Students' Course Perception

The Course Evaluation Scale (CES) scores of students who received education according to different teaching methods are presented in Table 8.

Table 8. Course Evaluation Scale Mean Scores

	Course		Instructor		Method-Technique		Assessment and Evaluation		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD
Experiment 1	3.91	0.43	4.80	0.21	4.68	0.18	4.47	0.62	4.34	0.25
Experiment 2	4.21	0.64	4.89	0.21	4.98	0.09	4.74	0.37	4.56	0.33
Control	3.43	0.62	4.54	0.43	4.13	0.33	4.21	0.55	3.91	0.37

When both the general scores and the sub-factor scores related to perception of the students are examined, it is seen that the students in the experiment 2 group have the highest scores. While the scores of the experiment 1 group are close to the experiment 2 group, it was determined that the students in the control group have lower perception scores than both experimental groups in all factors. It was observed that the students' scores were close to normal distribution (Table 9) and the group variances were homogeneous (Levene Statistic = 2.218, p = 0.116). The course perception scores of students in different groups are given in Table 10.

Table 9. Skewness and Kurtosis Values of Students' CES Scores

	Skewness		Kurtosis	
	Statistic	Std. Error	Statistic	Std. Error
Experiment 1	-0.68	0.47	-0.34	0.92
Experiment 2	0.01	0.46	-0.86	0.89
Control	-1.10	0.45	0.81	0.87

Table 10. ANOVA Results regarding General Course Perception Scores

Variance Source	Sum of Squares (SS)	Degrees of Freedom (df)	Mean of Squares (MS)	F	p	Post Hoc
Between Groups	5.446	2	2.723	26.977	0.000	C-E1*
Within Groups	7.470	74	0.101			C-E2*
Total	12.916	76				

Note: Significant at p < .01 level, C= Control group, E1= Experiment 1, E2= Experiment 2

As a result of ANOVA analysis, it was found that there was a statistically significant difference between the groups in terms of general course perception scores (F (2,74) = 26.977, p < 0.001). According to the Post-Hoc analysis results, the general course perception scores of the students in both experiment 1 (application-based in-class activities) and experiment 2 (GenAI supported

activities) groups were significantly higher than those of the students in the control group (curriculum-based standard teaching). The ANOVA results regarding the students' scores on the scale sub-factors are presented in Table 11.

Table 11. ANOVA Results regarding Scale Sub-factor Scores

Variance Source	Sum of Squares (SS)	Degrees of Freedom (df)	Mean of Squares (MS)	F	p	Post Hoc
Course						
Between Groups	7.919	2	3.959	12.102	0.000	C-E1**
Within Groups	24.210	74	0.327			C-E2*
Total	32.129	76				
Teacher						
Between Groups	1.621	2	0.810	9.183	0.000	C-E1**
Within Groups	6.530	74	0.088			C-E2*
Total	8.151	76				
Method-Technique						
Between Groups	9.508	2	4.754	98.804	0.000	C-E1*
Within Groups	3.560	74	0.048			C-E2*
Total	13.068	76				E1-E2*
Exam						
Between Groups	3.606	2	1.803	6.565	0.002	K-D2*
Within Groups	20.323	74	0.275			
Total	23.929	76				

*Note. * Significant at p < .01 level, ** Significant at p < .05 level, C= Control group, E1= Experiment 1, E2= Experiment 2*

As a result of ANOVA analysis, significant differences were found between the groups in the students' perception scores regarding the course and instructor sub-factors. According to the Post-Hoc analysis results, the course and instructor sub-factor scores of the students in the control group were significantly lower than those of the students in the experiment 2 group at the $p < .05$ level, and lower than those of the students in the experiment 1 group at the $p < .01$ level. In the method-technique sub-factor, a significant difference was found between the students in control group and both experimental groups in favor of the experimental groups ($p < .01$). Additionally, a significant difference was found between the students in the experiment 1 group and the students in the experiment 2 groups in this sub-factor, in favor of the experiment 2 group ($p < .01$). In the assessment and evaluation sub-factor, a statistically significant difference was found only between the students in group control and group experiment 2, in favor of experiment 2 ($p < .01$).

These findings reveal that different teaching methods have a significant effect on students' course perceptions. It was determined that the perceptions of the students in the experimental groups, instructor and method-technique sub-factors were more positive compared to the students in the control group.

Findings Regarding the Relationship between Students' Course Perception Scores and Academic Achievements Scores

Table 12. The Relationship between CES Scores and Academic Achievement Test Scores of Students

Variables	N	M	SD	r	p
Academic Achievement Test Scores	77	78.51	11.87	0.174	0.129
Course Evaluation Scale Scores	77	4.29	0.41		

As seen in Table 12, there is a weak positive relationship between the students' course evaluation scale (CES) scores and their academic achievement test scores ($r = 0.174$, $p = 0.129$). However, this relationship was not found to be statistically significant. This result shows that there is no direct relationship between the students' course perceptions and their academic achievement.

Discussion

Recent studies suggest that the impact of technology-supported and application-based learning may not be fully reflected in short-term measurement (Baidoo-Anu & Ansah, 2023; Hsu & Ching, 2023). In line with this, our findings indicate that although no significant difference was observed in academic performance, the trend favors application-based and GenAI-supported approaches. Reichert et al. (2020) also emphasized that individuals' familiarity with digital software tools can have decisive effects on students' performance. Therefore, the absence of a significant difference in achievement can be considered a result of short-term measurement. In the long term, it can be expected that academic achievement differences will become more pronounced as students become more accustomed to technology-supported learning styles and self-regulated processes.

In this study, students in both experimental groups reported significantly higher scores in general and sub-dimensions of course perception compared to the control group. These findings show that application-based and GenAI-supported learning processes strongly impact student course perceptions. This finding also supports the emphasis in the literature that software literacy and digital literacy are among the basic components of contemporary learning environments (Aydınlar et al., 2024; Reichert et al., 2020). Khoo et al. (2017) emphasize that students need to develop critical and conceptual perspectives beyond being merely digital tool users. The finding that GenAI-supported learning processes and application-based in-class activities increase students' course perception scores is consistent with the principle of active student participation in learning and taking responsibility for learning, as highlighted by constructivist learning theory (Duffy & Jonassen, 1992). The integration of information and communication technologies into the learning process makes it possible to implement constructivist practices more functionally (Kılıç Çakmak et al., 2017). Pavlik (2025) states that GenAI offers significant opportunities for designing participatory learning processes within the framework of constructivist theory. In this context, it becomes a pedagogical learning partner, turning students into active participants in learning environments.

The finding that GenAI-supported learning environments positively affect students' course perception is also parallel to the literature (Bahroun et al., 2023; Lim et al., 2023). Similarly, students tend to perceive GenAI as a personalized, time-efficient, and easily accessible learning assistant, reflecting a positive attitude towards its integration into education (Monib et al., 2025; Obenza et al., 2024). GenAI tools provide students with personalized learning experiences that meet their individual needs. It supports learning processes by providing continuous feedback through formative assessment practice. In the study conducted by Yilmaz and Yilmaz (2023), it was revealed that GenAI-supported education increased students' cognitive thinking skills, programming self-efficacy, and motivation.

In the curriculum-based control group, programming instruction was delivered through theoretical explanations and textbook-based materials. Control group, the instruction followed a teacher-centered "*demonstrate-and-follow*" model. While students repeated the codes written by the instructor, they had limited opportunities to independently write or modify code themselves due to time constraints. As a result, the process relied heavily on passive observation rather than active engagement in programming. Considering that curriculum-based standard teaching cannot meet the needs of students due to time and resource limitations, GenAI-based solutions like ChatGPT can provide an important alternative (Lodge et al., 2023). These tools can overcome time and space limitations by providing individualized guidance and increasing students' active participation in the learning process (Hsu & Ching, 2023). In addition, one of the most challenging situations for students during out-of-class activities is not being able to reach the teacher for support when needed. Lack of feedback negatively affects students' homework completion behaviors and time management, indirectly decreasing success (Núñez et al., 2015). In addition, teachers' inability to adequately recognize the difficulties experienced by students, combined with the lack of this support, leads to a more negative perception of the process from the student's perspective (Hong et al., 2011). At this point, providing GenAI support in out-of-class activities stands out as an important opportunity for

students to access guidance when they need it. In this study, prompts were given to the student's ready-made. Providing accurate, clear, and relevant prompts is also a critical requirement for the effective use of GenAI tools (Bozkurt & Sharma, 2023). Students' possession of these skills will contribute to the deepening of learning by supporting critical thinking, problem solving, and creativity.

In conclusion, the findings of this study show that in-class application-based activities and GenAI-supported out-of-class activities, compared to curriculum-based instruction, strengthen students' course perceptions scores across all sub-dimensions (course, instructor, method-technique, and assessment). While no statistically significant differences were found in achievement scores among the groups, both experimental groups showed higher average scores than the control group. Although the short-term academic achievement effects may not yet be significant, they may become more visible over time as students adapt to more personalized and participatory learning methods. In this context, the integration of GenAI tools in education should be considered not only as a technological innovation but also as a pedagogical transformation, especially in programming instruction. Establishing a structure that encourages students to take responsibility for their learning and supports constructive and personalized learning experiences will ensure more effective and sustainable learning outcomes in educational environments.

Conclusion and Recommendations

The findings of this study show that application-based in-class activities and ChatGPT-supported activities strengthen students' course perceptions, but their effects on academic achievement are not evident in the short term. The increase in student perception highlights the importance of an environment that encourages individual participation and responsibility for learning within the framework of constructive learning theory. GenAI-supported learning applications stand out as an effective alternative, especially for educational environments with time and space constraints, by offering personalized guidance and instant feedback. In this context, the integration of GenAI tools into educational environments may be considered as a pedagogical way to support students with application-based learning experiences in out-of-class.

Based on the significant differences observed in students' course perception levels, this research recommends that application-based lesson hours be expanded in the curriculum. Students in both in-class activities and GenAI-supported learning conditions reported more positive perceptions of the course, instructor, and instructional methods, highlighting the need to foster active and engaging learning environments. Especially in courses such as "*Information Technologies and Software*", course weekly lesson hours can be increased, and application-based in-class activities opportunities can be provided. In cases where in-class hours are limited, moving application-based activities to the out-of-class environment supported by GenAI-based methods can be considered as an alternative. To encourage students' familiarity with software tools and the development of their software literacy, GenAI-supported activities can be planned from early on. In addition, teachers' pedagogical competencies can be improved so that they can provide effective prompts and sample application scenarios to their students. Additionally, for students to utilize GenAI tools, they must develop the skills to create accurate, clear, and relevant prompts when interacting with these tools. As a result, rather than seeing GenAI tools merely as a support tool, using them as a component that will strengthen students' active participation and meaningful learning processes will pave the way for permanent and sustainable gains in education.

Limitations and Future Research

This study has several limitations. First, the short-term measurement of academic achievement and course perception prevented the evaluation of long-term effects. The absence of a pre-test limits internal validity, as prior group equivalence could not be fully ensured despite matching based on previous course grades. Additionally, individual differences in students' familiarity with digital tools may have influenced learning outcomes. Conducting the study within a single course and grade level limits external validity and generalizability. Finally, relying solely on self-reported perception data suggests the need for more objective measures in future research.

Ethics Statement

There are no ethical issues with the publication of this article.

Conflicts of Interest

There are no conflicts of interest.

ORCID

Necati Taşkın https://orcid.org/0000-0001-8519-6185

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Method Validation and Calculation of Measurement Uncertainty for Salt Determination in Cheese by Mohr Method

Yasin Yakar[1], Elif Esra Altuner[2], Tuba Tekeli[3], Yener Tekeli[4], Merve Özdemir[5], Tuğçe Çelik[5]

[1] University of Harran, Vocational School of Organised Industrial Zone, Department of Chemistry and Chemical Processing Technologies, Sanliurfa
[2] University of Kocaeli, Vocational School of Europe, Program of Medical Laboratuary Tecniques, Department of Medical Services and Techniques, Health and Technology, Kocaeli
[3] University of Adiyaman, Vocational of Basic Sciences, Department of Chemistry and Chemical Processing Techniques, Adiyaman
[4] University of Adiyaman, Faculty of Pharmacy, Department of Pharmaceutical Technology, Adiyaman
[5] University of Harran, Faculty of Engineering, Department of Food Engineering, Sanliurfa

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Abstract

Validation studies were conducted to verify the validity of the Mohr method, which is one of the most common methods for salt determination in the laboratory. Precision (repeatability and reproducibility) and accuracy are method validation parameters. Relative standard deviation (RSD) values obtained under reproducibility and repeatability conditions were compared with concentration-dependent precision values and the results were appropriate. The accuracy study was carried out using a standard reference substance. The t-test was used to determine whether the results were close to the true value and the results were found to be appropriate. As a result, the validation studies of the Mohr method were completed and are valid for our laboratory. A study on the measurement uncertainty of cheese salt was also conducted. Therefore, Urfa cheese and kashar cheese were preferred. The applied analysis method determined the uncertainty components known as weight, volume, precision, and accuracy. Then, the expanded uncertainty was calculated by combining the uncertainties resulting from these uncertainties. The expanded uncertainty is U(salt) =0.028.

Keywords: cheese, salt, validation, measurement, Mohr method

Mohr Metodu ile Peynirde Tuz Tayini İçin Ölçüm Belirsizliğinin Hesaplanması ve Metot Doğrulaması

Öz

Laboratuvarda tuz tayini için en yaygın kullanılan yöntemlerden biri olan Mohr yönteminin geçerliliğini doğrulamak için validasyon çalışmaları yapılmıştır. Kesinlik (tekrarlanabilirlik ve tekrar üretilebilirlik) ve doğruluk yöntem validasyon parametreleridir. Tekrar üretilebilirlik ve tekrar üretilebilirlik koşulları altında elde edilen Bağıl Standart Sapma (RSD) değerleri konsantrasyona bağlı kesinlik değerleri ile karşılaştırılmış ve sonuçlar uygun bulunmuştur. Doğruluk çalışması standart referans madde kullanılarak yapılmıştır. Sonuçların gerçek değere yakın olup olmadığını belirlemek için t-testi kullanılmış ve sonuçlar uygun bulunmuştur. Sonuç olarak Mohr yönteminin validasyon çalışmaları tamamlanmış ve laboratuvarımız için geçerlidir. Peynir tuzunun ölçüm belirsizliği üzerine bir çalışma da yapılmıştır. Bu nedenle Urfa peyniri ve kaşar peyniri tercih edilmiştir. Uygulanan analiz yöntemi ile ağırlık, hacim, kesinlik ve doğruluk olarak bilinen belirsizlik bileşenleri belirlenmiştir. Daha sonra bu belirsizliklerden kaynaklanan belirsizlikler birleştirilerek genişletilmiş belirsizlik hesaplanmıştır. Genişletilmiş belirsizlik U(tuz)=0,028'dir.

Anahtar Kelimeler: peynir, tuz, doğrulama, ölçüm, Mohr metodu

Sorumlu Yazar / Corresponding Author: Elif Esra Altuner elifesraaltuner@gmail.com

Introduction

The primary purpose of chemical measurement is to make decisions based on the measurement result. It is taken into account when deciding on the compliance of a product with certain standards, quality standards, control of the production process, standards for legal decisions, commercial evaluation, and classification (Anderson et al., 1999). Chemical measurement results should be accurate, reliable, repeatable, and comparable on a national and international scale (Bulska & Lipiński, 2018). Reliable analysis is performed using methods and tools such as standard test procedures, internationally developed standard methods (ASTM-American Society for Testing and Materials, ISO-International Organization for Standardization, EPA-US Environmental Protection Agency, AOAC-American Official Analytical Chemist), calibration, performance tests, laboratory accreditation, proficiency tests and chemical metrology (Akdağ, 2004).

One or more organizations can accredit laboratories in a country. Law No. 4457 authorized the Turkish Accreditation Agency (TÜRKAK) to accredit laboratories in our country (Uras, 2009). Today, TS EN ISO/IEC 17025 General Conditions for the Competence of Testing and Calibration Laboratories are required for the accreditation of testing and calibration laboratories. This standard has been approved worldwide. ISO/17025 Laboratory accreditation standards consist of two main parts: technical conditions and quality management standards (Krismastuti & Habibie, 2022). Similar conditions to the quality management system specified in the ISO 9000 quality standard have been adapted for the laboratory. As a result, institutions or laboratories that implement a quality system in accordance with the ISO 9000 standard can spend less effort to meet these requirements (Douglas et al., 2003). Laboratory accreditation uses an evaluation system consisting of three basic issues (Alper, 2004). These are measurement uncertainty, method validation and traceability of results (Inal & Topkaya, 2010).

Validation or validity is the whole of the operations performed to show that a device, method, or system works in accordance with the specified conditions (Çelebiler et al., 2011). The principles of method performance depend on the purpose and scope of the method to be applied (Menditto et al., 2007). Precision, accuracy, selectivity, linearity and measurement range, sensitivity, and robustness are the validity indicators of the methods (Araujo, 2009). The first application of a method in a laboratory, the development of a new method for analysis, the modification of a method in use, its application in another laboratory, or the change in the person applying or the device used are known as method validity (Ertaş & Kayalı, 2005).

Due to the uncertain effects of random effects, uncertain data determine the limits within which values can be encountered around the result. A measurement uncertainty consists of a series of uncertainties combined. Uncertainty calculations are necessary to improve the quality of food laboratories (AOAC 1998).

The Mohr method is simple, cheap and fast. To our knowledge, no validation or measurement uncertainty study has been conducted on cheese using this method. In this study, validation studies of the analytical method for the determination of salt in cheese according to the Mohr method were carried out and the measurement uncertainty was calculated.

Material & Method

Materials

Two different cheese samples taken from local markets were used to investigate the validation and measurement uncertainty of the salt determination method. One was kashar cheese with less salt content, the other was Urfa cheese with more salt. These samples were selected in two different varieties and different concentrations to cover all cheese types in the study. 0.1 N Silver nitrate ($AgNO_3$) solution and 5% potassium chromate (K_2CrO_4) solution were prepared. The $AgNO_3$ and K_2CrO_4 required to prepare these solutions were supplied by Sigma & Aldrich.

Analysis Method

In this study, the Mohr method, one of the most preferred methods, was used for method validation and measurement uncertainty calculation of salt determination in cheese. Approximately five grams of the homogenized sample was weighed into a conical flask, some hot pure water was added, and the mixture was shaken vigorously for five to ten minutes. The solution was filtered through the filter paper into a 500 mL volumetric flask. The conical flask was washed four to five times with hot water and then placed on the filter paper. This allowed the salt to remain in the conical flask and the filter paper to pass into the water. After the filtrate in the volumetric flask had cooled completely, it was combined with pure water up to the volume line. Then, 25 milliliters were taken into the conical flask and 2-3 drops of K_2CrO_4 solution were added. Burette was filled with $AgNO_3$ and zero was set. The sample was titrated with $AgNO_3$ (0.1 N) solution until a brick-red color developed (Sezey & Adun, 2019). Percentage of salt was calculated according to the equation 1 (Eq.1).

$$Salt\ \%\ (g) = 0.00585xVxNxDFx100/m \quad \text{(Eq.1)}$$

[V = Volume of $AgNO_3$ solution spent (mL), N = Concentration of adjusted $AgNO_3$ solution , m = Amount of sample taken (g), DF= Dilution factor (X g of sample was diluted into a 500 mL volumetric flask. 25 mL of this solution was also taken. In this case, the dilution factor is 500/25 = 20)].

Results & Discussion

Precision and Validation Studies

Validation studies were carried out in the laboratory to validate the Mohr method, one of the most widely used methods for salt determination in cheese. Kashar and Urfa cheese were preferred for the method's applicability to all cheese types. Certified reference material was used for the accuracy study. The method validation parameters were precision (repeatability, reproducibility) and accuracy.

Repeatability

For repeatability, the Mohr method performed ten studies on the selected cheese samples on the same day. Tables 1 and table 2 show the methods for calculating the mean, standard deviation, and relative standard deviation of the obtained data. Table 1 compares the relative standard deviation (RSD) values obtained under repeatability conditions with the concentration-dependent precision values. The Grubb test was applied to the within-group data to determine the different values in the analysis results. Since all % RSD values obtained under repeatability conditions were smaller than the 1.8 % RSD value given in the concentration-dependent precision values table, they were interpreted as being by the RSD values obtained under repeatability conditions.

Table 1. Studies on Salt Determination in Kashar Cheese of the 1st and 2nd Analysts under Repeatability Conditions

Number of Repeatability	1st Analyst	2nd Analyst
1	2.75	2.68
2	2.70	2.72
3	2.60	2.77
4	2.65	2.72
5	2.77	2.72
6	2.75	2.68
7	2.65	2.80
8	2.75	2.72
9	2.70	2.78
10	2.67	2.77
Average	2.70	2.74
Standard deviation	0.054	0.042
RSD	0.020	0.015
RSD %	1.56	1.55
Grubb top	1.297	1.418
Grubb down	1.853	1.418
Grub criterion	2.29	2.29
Evalution	Suitable	Suitable

Table 2. Studies on Salt Determination in Urfa Cheese of the 1st and 2nd Analysts under Repeatability Conditions for 3rd Day

Number of Repeatability	1st Analyst	2nd Analyst
1	7.09	7.12
2	7.05	7.03
3	7.14	7.12
4	7.10	7.12
5	7.14	7.07
6	7.00	7.03
7	7.14	7.12
8	7.14	7.17
9	7.14	7.07
10	7.18	7.12
Average	7.11	7.10
Standard deviation	0.053	0.045
RSD	0.007	0.006
RSD %	0.74	0.64
Grubb top	1.329	1.544
Grubb down	2.088	1.544
Grub criterion	2.29	2.29
Evalution	Suitable	Suitable

Reproducibility

For reproducibility, ten replicates were performed on selected cheese samples using the Mohr method on various days. The mean, standard deviation, and relative standard deviation of the data obtained in Tables 3, 4, 5, and 6 were calculated. The table shows the agreement between the relative standard deviation (RSD) values obtained under reproducibility conditions and the concentration-dependent precision values. The RSD values were compared with the RSD values. According to the analysis results stated in the tables, all RSD values obtained under reproducibility conditions were interpreted as suitable since the concentration-dependent precision values were less than 1.8 % RSD.

Table 3. Reproducibility Study on Kashar Cheese Sample (1st Analyst)

Number of Repeatability	a	b	X	a-b	(a-b)/X	((a-b)/X)²
1 (1st day)	7.138	7.080	7.109	0.058	0.008	0.000
2 (1st day)	7.138	7.100	7.119	0.038	0.005	0.000
3 (1st day)	7.046	7.060	7.053	-0.014	-0.002	0.000
4 (1st day)	7.138	7.100	7.119	0.038	0.005	0.000
5 (2nd day)	7.000	7.060	7.030	-0.060	-0.009	0.000
6 (2nd day)	7.138	7.120	7.129	0.018	0.003	0.000
7 (2nd day)	7.184	7.100	7.142	0.084	0.012	0.000
8 (3rd day)	7.138	7.040	7.089	0.098	0.014	0,000
9 (3rd day)	7.138	7.100	7.119	0.038	0.005	0.000
10 (3rd day)	7.184	7.120	7.152	0.064	0.009	0.000
Total						0.001
RSD						0.006
RSD %						0.6

a: First analysis result, b: Second analysis result and X: Mean value.

Table 4. Reproducibility Study on Kashar Cheese Sample under Different Days (2nd Analyst)

Number of Repeatability	a	B	X	a-b	(a-b)/X	((a-b)/X)²
1 (1st day)	7.138	7.100	7.119	0.038	0.005	0.000
2 (1st day)	7.138	7.120	7.129	0.018	0.003	0.000
3 (1st day)	7.138	7.120	7.129	0.018	0.003	0.000
4 (1st day)	7.000	7.060	7.030	-0.060	-0.009	0.000
5 (2nd day)	6.954	7.000	6.977	-0.046	-0.007	0.000
6 (2nd day)	7.138	7.120	7.129	0.018	0.003	0.000
7 (2nd day)	7.046	7.080	7.063	-0.034	-0.005	0.000
8 (3rd day)	7.138	7.080	7.109	0.058	0.008	0.000
9 (3rd day)	7.092	7.120	7.106	-0.028	-0.004	0.000
10 (3rd day)	7.046	7.080	7.063	-0.034	-0.005	0.000
Total						0.000
RSD						0.004
RSD %						0.4

Table 5. Reproducibility Study on Urfa Cheese Sample (1st Analyst)

Number of Repeatability	a	b	X	a-b	(a-b)/X	((a-b)/X)²
1 (1st day)	2.68	2.70	2.69	-0.02	-0.01	0.00
2 (1st day)	2.77	2.82	2.80	-0.05	-0.02	0,00
3 (1st day)	2.74	2.72	2.73	0.02	0.01	0,00
4 (1st day)	2.68	2.68	2.68	0.00	0.00	0,00
5 (2nd day)	2.75	2.72	2.74	0.03	0.01	0,00
6 (2nd day)	2.70	2.68	2.69	0.02	0.01	0.00
7 (2nd day)	2.69	2.74	2.72	-0.05	-0.02	0.00
8 (3rd day)	2.72	2.73	2.73	-0.01	0.00	0.00
9 (3rd day)	2.68	2.70	2.69	-0.02	-0.01	0.00
10 (3rd day)	2.72	2.75	2.74	-0.03	-0.01	0.00
Total						0,001
Total						0.001
RSD						0.008
RSD %						0.8

a: First analysis result, b: Second analysis result and X: Mean value.

Table 6. Reproducibility Study on Urfa Cheese Sample under Different Days (2nd Analyst).

Number of Repeatability	a	b	X	a-b	(a-b)/X	((a-b)/X)²
1 (1st day)	2.77	2.72	2.74	0.05	0.02	0.00
2 (1st day)	2.72	2.70	2.71	0.02	0.01	0.00
3 (1st day)	2.77	2.70	2.73	0.07	0.02	0.00
4 (1st day)	2.77	2.72	2.74	0.05	0.02	0.00
5 (2nd day)	2.70	2.72	2.71	-0.02	-0.01	0.00
6 (2nd day)	2.74	2.70	2.72	0.04	0.02	0.00
7 (2nd day)	2.75	2.74	2.74	0.01	0.00	0.00
8 (3rd day)	2.75	2.76	2.75	-0.01	0.00	0.00
9 (3rd day)	2.66	2.70	2.68	-0.04	-0.01	0.00
10 (3rd day)	2.71	2.75	2.73	-0.04	-0.01	0.00
Total						0.002
RSD						0.010
RSD %						1.0

a: First analysis result, b: Second analysis result and X: Mean value.

All RSD values obtained under reproducibility conditions since it is smaller than the RSD value of 1.8% given in the table of precision values as a function of concentration (Table 7), the RSD values obtained under reproducibility conditions are interpreted as appropriate.

Table 7. Comparison of Concentration-Dependent Precision Value (AOAC, 1998).

Percent of Analyst Concentration (%)	Analyst Ratio	Unit	RSD %
100	1	100 %	1.3
10	10^{-1}	10 %	1.8
1	10^{-2}	1 %	2.7
0.1	10^{-3}	0.1 %	3.7
0.01	10^{-4}	100 ppm	5.3
0.001	10^{-5}	10 pp	7.3
0.0001	10^{-6}	1 ppm	11
0.00001	10^{-7}	100 ppb	15
0.000001	10^{-8}	10 ppb	21

Analysis of Accuracy

For the accuracy parameter, 10 replicate analyses were performed using the reference material (white cheese) and the mean, standard deviation and systematic error of the values obtained were calculated (Table 8). The t-test was performed to check whether the systematic error calculated according to the certificate value was significantly different from the actual value and the t-value was calculated.

Table 8. Standard Reference Material (white cheese) Analysis Results

Number of Repeatability	Salt (%)
1	3.34
2	3.29
3	3.33
4	3.33
5	3.29
6	3.22
7	3.24
8	3.2
9	3.33
10	3.12
Real value	3.31
Found value	3.27
Relative error	0.012
Standard deviation	0.072
t value	1.789
t critical value	2.262

From the t-test table in the literature, the critical t value at 9 degrees of freedom (n-1) in the 95 % confidence interval was found to be 2.262. Since the calculated value was 1.789<2.262, it was interpreted as there was no significant difference between it and the certificate value.

Sezey and Adun (2019) carried out validation studies of the Mohr titration method for the determination of salt content in olive and/or olive brine. The method was successfully validated as its accuracy (70-120%) and precision (RSD 5%) were within acceptable ranges.

Calculation of Measurement Uncertainty

The uncertainty components of the applied analysis method are weighing, volume, precision and accuracy.

The uncertainty of the precision balance used in the studies was given as ± 0.001. The standard uncertainty was found as 0.001/√3 = 0.0006 with a rectangular distribution.

The 5 mL pipette calibration certificate value is given as ± 0.05 ml. The standard uncertainty is found as 0.05/√3 = 0.028 with a rectangular distribution. The 10 mL pipette calibration certificate value is given as ± 0.1 mL. The standard uncertainty is found as 0.1/√3 = 0.057 with a rectangular distribution. In the studies conducted, the accuracy relative error was calculated as 0.012 (Table 8). Volume uncertainty values are given in Table 9.

Table 9. Volume Uncertainty Values

Compound	Value	Standard Uncertainty	Relative Standard Uncertainty
Volume of pipette (ml)	5	0.028	0.0056
Volume of pipette (ml)	10	0.057	0.0057
Total volume uncertainty	-	-	0.008

The combination of RSDs obtained from repeatability and reproducibility studies in Urfa and kashar cheese should be used to determine the uncertainty of precision. The following eqution 2 (Eq.2) was used to achieve this. The uncertainty due to precision was found to be U_{total} = 0.0008.

$$RSD_{(compound)} = \sqrt{(\sqrt{(RSD_1)^2} \times \sqrt{df_1} + \sqrt{(RSD_2)^2} \times \sqrt{df_2} + \ldots + \sqrt{(RSD_n)^2} \times \sqrt{df_n})} / \sqrt{(df_1+df_2df_3+\ldots+df_n)} \quad \text{(Eq.2)}$$

[RSD: Relative standard deviation, df: Degrees of freedom (df=n-1; n: Number of repetitions)].

Total Uncertainty

The total uncertainty was calculated by combining the uncertainty results from weighing, volume, precision and accuracy using the formula below.

Total uncertainty (U) was calculated as 0.014 according to equation 3 (Eq.3).

$U = \sqrt{(U_{weigh})^2 + (U_{volume})^2 + (U_{certainity})^2 + (U_{truth})^2}$ *(Eq.3)*

Expanded Uncertainty

The expanded uncertainty was calculated according to equation 4 and 5 (Eq.4; Eq.5) and found to be 0.028. At this point, it is possible to give the values of our study as the result of the report in the form of equation 6 (Eq.6).

Expanded Uncertainty (U_{top})= *Total standard uncertainty* (Utop) *x k* (Eq.4)

k= 2 (%95 confidence interval)

$U_{salt}=k \times U_{(Protein\text{-}Relative\ Std.Uncertainity)}$ (Eq.5)

U_{salt} = 2 x 0.014

U_{salt} = 0.028

Result (%) = Analysis Result ± (Analysis Result x Expanded Uncertainty) (Eq.6)

Conclusion

Validation studies were conducted to verify the validity of the Mohr method, which is one of the most common methods for salt determination in the laboratory. Therefore, Urfa cheese and Kashar were preferred. Precision (repeatability and reproducibility) and accuracy are the method validation parameters. The relative standard deviation (RSD) values obtained under the conditions of reproducibility and repeatability were compared with the concentration-dependent precision values and the results were found to be appropriate. The accuracy study was carried out using a standard reference substance. The t-test was used to determine whether the results were close to the true value and the results were found to be appropriate. As a result, the validation studies of the Mohr method were completed and are valid for our study. A study on the measurement uncertainty of cheese salt was also conducted. The applied analysis method determined the uncertainty components including volume, precision, weight, and accuracy. Then, the expanded uncertainty was calculated by combining these components. The expanded uncertainty is U(salt) = 0.028

Author Contributions

Yasin Yakar contributed to data collection, writing, and analysis. *Elif Esra Altuner* participated in data collection and writing. *Yener Tekeli* and *Tuba Tekeli* contributed to writing and manuscript review. *Merve Özdemir* and *Tuğçe Çelik* were involved in data collection and analysis. All authors have read and approved the final version of the manuscript.

Ethic

There is no any ethical issue in publishing this article.

Conflicts of Interest

The authors declare no conflicts of interest.

ORCID

Yasin Yakar https://orcid.org/0000-0003-3297-3379

Elif Esra Altuner https://orcid.org/0000-0001-7663-6898

Tuba Tekeli https://orcid.org/0009-0008-6429-8455

Yener Tekeli https://orcid.org/0000-0003-1524-457X

Merve Özdemir https://orcid.org/0000-0002-7750-1976

Tuğçe Çelik https://orcid.org/0009-0004-7885-0491

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