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Yayın Türü: Yerel Süreli
Akademik Gıda Dergisi Hakemli Dergidir.

Son yıllarda tüm dünyayı etkileyen ve art arda gelen ekonomik, sosyal, doğal ve epidemiyolojik krizler, ekonomideki yapısal değişikliklerin acil ve her şeyden önce gerçek anlamda uygulanması ihtiyacına dikkat çekmiştir. Söz konusu yapısal değişikliklerden biri, ulusal ekonomileri, çevreyi en az şekilde etkileyen, aynı zamanda modern ve rekabetçi ekonomik sistemlere dönüştürmeyi amaçlayan yeşil dönüşümdür. Yeşil dönüşüm, gelecek nesiller için yüksek bir yaşam kalitesini garanti etmek ve kaynakların etkin ve akılcı kullanımını sağlamak amacıyla ekonomik büyümeyi çevreye duyarlılıkla birleştirmek olarak tanımlanmaktadır. Bu kavram; çevreye duyarlı yeşil teknolojilerin geliştirilmesi ve kullanılmasını, sürdürülebilirlik kavramının yaşam biçimi haline getirilmesini, doğal kaynakların korunmasına yönelik politika, uygulamalar ve yasal düzenlemelerin geliştirilmesini, ayrıca toplumun çevre dostu teknolojilerin kabulüne yönelik tutumunu değiştirmeyi amaçlayan diğer faaliyetlerin gerçekleştirilmesini içermektedir.

Yeşil dönüşüm uzun vadeli bir süreç olup nihai hedef modern iş rekabetinin temeli haline gelen yeşil pazarların oluşturulmasıdır. Çevre dostu ürün, hizmet ve teknolojilere talebin artması, insanlığın konu ile ilgili farkındalığının artarak çevreye duyarlı tutum ve davranışlar geliştirmesi, sürdürülebilir çevre için yasal düzenlemelerin aktif ve güçlü bir şekilde uygulanması yeşil dönüşüm için önemli mihenk taşlarıdır.

Yeşil dönüşüme katkı sağlayacak bilimsel çalışmalar dünya genelinde desteklenmekte olup, son yıllarda yükseköğretim kurumlarının dünya genelindeki sıralamalarında da bu faaliyetler puanlanarak kurumların yeşil dönüşüme yaptıkları katkılar değerlendirilmektedir. Birleşmiş Milletlere üye ülkeler, tüm insanlığın karşı karşıya olduğu sorunların çözümü için birbiri ile bağlantılı 17 Sürdürülebilir Kalkınma Amacına (yoksulluğu son, açlığa son, sağlık ve kaliteli yaşam, nitelikli eğitim, temiz su ve sanitasyon, erişilebilir ve temiz enerji, sorumlu üretim ve tüketim, iklim eylemi vb.) 2030 yılına kadar erişilmesi için desteğini sürdürmektedir.

Ülkemiz ve dünya genelinde yürütülen yeşil dönüşüm çalışmalarına katkı sağlama amacıyla bir araya gelen Sidas Medya Ltd. Şti. ve İzmir Kalkınma Ajansı (İZKA), Akademik Gıda dergisinin 22. yayın yılında Yeşil Dönüşüm Özel sayısı yayınlanması için iş birliği yapma kararı almıştır. Söz konusu iş birliğinin bir ürünü olan Yeşil Dönüşüm Özel sayısında ülkemiz ve yurt dışından farklı kurum ve kuruluşlarda görev yapan bilim insanları tarafından hazırlanan 5 araştırma makalesi ve 4 derleme makale olmak üzere 9 makale yer almaktadır.

Yeşil Dönüşüm Özel Sayısının hazırlanmasındaki katkı ve destekleri için İzmir Kalkınma Ajansı (İZKA) yöneticilerine ve personeline, bu özel sayının oluşmasında katkıda bulunan; çalışmalarını yayımlanmak üzere dergimize gönderen yazarlara ve bu çalışmaları titizlikle değerlendiren yayın kurulu üyelerimiz ve hakemlerimize teşekkürlerimizi sunuyoruz.

Saygılarımızla.

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İZMİR KALKINMA AJANSI

Değerli Okuyucular,

Doğal kaynakların hızla tükendiği, iklim değişikliğinin küresel etkilerinin giderek daha fazla hissedildiği ve sürdürülebilirlik kavramının her alanda önem kazandığı bir dönemdeyiz. Bu bağlamda, gıda ve tarım sektörünün yeşil dönüşüme katkısı hem yerel hem de küresel ölçekte büyük bir önem taşımaktadır.

İzmir Kalkınma Ajansı olarak kurulduğumuz günden bu yana, bölge kaynaklarının çevreye duyarlı bir şekilde kullanılması için üreticilere ve sanayicilere gerekli bilgi birikimi ve desteği sağlamaya büyük özen göstermekteyiz. Bu kapsamda, temiz enerji ve temiz teknolojiler alanında sunduğumuz politikalarla İzmir'in yeşil ve mavi büyüme eksenlerinde dönüşümünü hızlandırmayı hedefleyen stratejik adımlar atarak bölgenin sürdürülebilir kalkınma hedefleri doğrultusunda çevre dostu üretim ve hizmet sunumunun yaygınlaştırılmasını amaçlayan birçok öncü ve özgün çalışma gerçekleştirmekteyiz.

2022 yılında yayımladığımız "İzmir'de Yeşil Dönüşüm ve Mavi Fırsatlar Perspektifi" çalışması, İzmir'deki tarım ve sanayi sektörlerinde yeşil dönüşümü başlatmak için öncelikli sektörleri ve mekânsal odakları belirleyerek bu dönüşümün sağlayacağı ekonomik, sosyal ve çevresel faydaları detaylı bir şekilde ortaya koymaktadır. Özellikle tarımsal üretim ve gıda sanayi, İzmir'de yeşil dönüşüm etkisinin en belirgin şekilde hissedileceği sektörler olarak öne çıkarken bu sektörlerde sürdürülebilir üretim uygulamalarının yaygınlaştırılması büyük önem taşımaktadır. Bu çerçevede 2021 yılından itibaren uyguladığımız "İzmir Endüstriyel Simbiyoz Projesi" ile atıl kaynakların kullanımını sağlayacak endüstriler arası işbirlikleri geliştirmeyi ve üretimde kaynak verimliliğini artırmayı hedefliyoruz. Projenin bir bileşeni olarak ülkemizin ve bölgemizin endüstriyel simbiyoz alanında bilimsel araştırma ve yayın yapma kapasitesinin güçlendirilmesi için yürütülen doktora tezlerinin desteklemesi faaliyeti bu alanda önemli bir zemin oluşturmaktadır.

Ajans olarak İzmir'in yeşil dönüşümüne yönelik müdahale alanlarının başarıyla hayata geçirilmesinde, akademik çalışmaların, araştırmaların ve yayınların yol gösterici olacağına inanıyoruz. Bu vizyon doğrultusunda hazırladığımız "Akademik Gıda Dergisi Yeşil Dönüşüm Özel Sayısı", hem akademik hem de sektörel perspektiflerden İzmir'in yeşil dönüşüm sürecine katkı sunmayı amaçlayan çalışmaları bir araya getirmektedir. Dergimiz, özellikle endüstriyel simbiyoz ve sürdürülebilir üretim konularında yol gösterici bir çalışma olmayı hedeflemekte, gıda sektöründe çevre dostu üretim modellerini ve yeşil teknolojileri teşvik etmektedir. Bu özel sayının, doğal kaynakların sürdürülebilir yönetimi, çevreye duyarlı üretim tekniklerinin yaygınlaştırılması ve geleceğe yönelik stratejik adımların atılmasına katkı sağlamasını diliyoruz.

Sürdürülebilir bir geleceğe giden yolda, hep birlikte adım atmanın kaçınılmaz bir sorumluluk olduğuna inanıyoruz.

Saygılarımızla,

İzmir Kalkınma Ajansı

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Research Paper / Araştırma Makalesi

Water Reuse via Membrane Technology: A Case Study for Producing Cooling Water from Soft Drink Wastewater

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ABSTRACT

High volumes of water are used in the soft drink industry, where purification can be achieved via membrane technology, allowing it to be reused in operating cooling towers, steam boilers, and closed-loop systems. In this study, ultrafiltration (UF) and nanofiltration (NF) were applied to produce reclaimed water for cooling towers. In experimental studies conducted under a total recycle mode of operation, two UF membranes with molecular weight cut-offs (MWCO) of 10 kDa and 5 kDa, and one NF membrane were tested. The transmembrane pressure was set to 2 bars for UF and 4 bars for NF. Considering the water quality criteria for cooling towers, removal efficiencies were calculated for total suspended solids (TSS), turbidity, and chemical oxygen demand (COD). TSS and turbidity removal rates were 100% for both UF and NF; however, COD removal rates varied. In UF, feed and permeate COD concentrations were 718 - 796 mg/L and 255 - 286 mg/L, corresponding to a removal efficiency of 64-65%. On the other hand, in NF, the feed and permeate COD concentrations were 207 mg/L and 147 mg/L, indicating a 29% removal. Flux decline was not severe; it ranged from 10% to 20%. It was revealed that further treatment is required to meet the COD criteria of 75 mg/L for cooling towers.

Keywords: Cooling tower, Membrane processes, Nanofiltration, Soft drink wastewater, Ultrafiltration

Membran Teknolojisi ile Su Geri Kazanımı: İçecek Atıksuyundan Soğutma Suyu Üretimi Üzerine Örnek Bir Çalışma

ÖZ

Yüksek miktarda su kullanılan içecek sektörü atık suları membran teknolojisi ile arıtılarak soğutma kuleleri, buhar kazanları ve kapalı devre sistemlerin işletilmesinde tekrar kullanılabilmektedir. Bu çalışmada içecek üretimi atıksuyundan soğutma kuleleri için su elde etmek amacıyla ultrafiltrasyon (UF) ve nanofiltrasyon (NF) uygulanmıştır. Toplam geri çevrim modunda yürütülen deneysel çalışmalarda, moleküler ağırlık ayırma sınırı (MWCO) 10 kDa ve 5 kDa olan iki UF membranı ve ayrıca bir NF membranı test edilmiştir. Trans membran basıncı UF için 2 bar, NF için 4 bar olarak ayarlanmıştır. Soğutma kuleleri için su kalitesi kriterleri dikkate alınarak toplam askıda katı madde (AKM), bulanıklık ve kimyasal oksijen ihtiyacı (KOİ) için giderim verimleri hesaplanmıştır. UF ve NF için AKM ve bulanıklık giderimleri %100 olmuştur, ancak KOİ giderimleri değişkenlik göstermiştir. UF için besleme ve süzüntü suyunda KOİ konsantrasyonu sırasıyla 718-796 mg/L ve 255-286 mg/L olmuş; %64-65 giderim verimi elde edilmiştir. Öte yandan, NF besleme ve süzüntü suyunda ise KOİ konsantrasyonu sırasıyla 207 mg/L ve 147 mg/L olarak ölçülmüş, %29 giderim verimi elde edilebilmiştir. Akı azalması çok yüksek olmamış; %10 ile %20 arasında kalmıştır. Soğutma kuleleri için KOİ sınır değeri 75 mg/L olması nedeniyle, ilave arıtma işlemine ihtiyaç olduğu ortaya konmuştur.

Anahtar Kelimeler: İçecek atıksuyu, Membran prosesleri, Nanofiltrasyon, Soğutma kulesi, Ultrafiltrasyon

INTRODUCTION

The sustainability of freshwater resources is under threat due to the worldwide population growth, economic development, environmental pollution and climate change. Türkiye is among the water-stressed countries. The increased demand for water as a result of urbanization, agricultural production and industrial activities have negative impacts on water resources.

The leading sectors in water use in Türkiye can be classified as agriculture, industry and urban/domestic use. The States Hydraulic Works [1] reports that 77% of freshwater resources are used for agricultural production, and the remaining 23% is shared between industry and domestic use. According to Turkish Statistical Institute [2], a total of 19.2 billion m^3 of water was withdrawn in 2022; of which 56.8% was from the sea; 43.2% was from freshwater resources, including 22.1% underground and 21.1% surface water. 94% of the water withdrawn from the sea was provided for cooling purposes, corresponding to 10.2 billion m^3.

Ensuring water efficiency in agricultural, domestic and industrial water use is of great importance. In linear economy model, taking water from the primary source, using it in production, and discharging it into the receiving environment after treatment is the most common practice today. However, this is not sustainable anymore. By reclaiming wastewater through advanced purification, it is possible to create an alternative water resource, in accordance with circular economy model. In beverage industry facilities, wastewater is generated through production, cleaning, and by-products. Discharging this wastewater into the receiving environment not only creates a serious organic burden for the environment, but also exerts pressure on water resources by increasing water consumption.

Almost two-thirds of industrial water is used in food industry, and the beverage industry consumes high volumes of water [3]. During the production phase, approximately 3000 - 4500 g of conditioned water is required to produce 1000 g of beverage. The water footprint of a sugar-containing carbonated beverage in a PET-bottle has a water footprint of 150 to 300 liters of water per 0.5 liters of bottle [4]. High amounts of water use also results in high wastewater outputs. It may be possible to reduce this consumption with water recycling practices in the industry. The beverage industry requires good management of water consumption and discharge. By protecting water resources and reducing the load of organic waste discharged into the environment, deterioration of the biological and chemical structure of the receiving environments is prevented.

The amount of process water used in industrial facilities is constantly increasing. But not all the water used is for the final product. It is wasted for cooling, heating, cleaning, etc. Especially in the beverage industry, large volumes of wastewater are discharged into the receiving environment. The most suitable point for water reuse is cooling towers and boiler systems since the highest water consumption outside the product is in these operations. There are different cooling tower water quality requirements in literature covering cooling tower manufacturers, laboratories and national regulations (Table 1). To this end, the aim of this study is to produce cooling water from soft drink wastewater via membrane processes to meet the reuse requirements.

MATERIALS and METHODS

The wastewater samples were collected from the facility producing soft drinks in Elazığ city of Türkiye in 30 kg light-proof drums and kept in a cold room. The wastewater characteristics are given in Table 2. Wastewater from the facility generally originates from bottle washing and production. The flowrate of wastewater is about 400 m^3/day. UF and NF processes were applied to provide treatment to meet the cooling water quality. UF 10 kDa (commercial name GR90PP-Alfa Laval), UF 5kDa (commercial name ETNA- Alfa Laval) PES membranes and NF membranes were used in LabStak M20 membrane module in total recycle mode of filtration. Membranes were wetted in pure water for 24 h before the experiments. Rejection performance and fluxes were monitored during the experiment conducted at a trans membrane pressure (TMP) of 2 bars for UF and 4 bars for NF. Clean water fluxes were measured before and after wastewater filtration. Chemical cleaning was performed with NaOH.

Before starting the analyses, pre-treatment was performed using a coarse filter; particles in the wastewater samples were removed. Then, total hardness was measured by titrimetric methods (Standart methods: 2340) [5], using Merck brand titration kit. Turbidity (Standart Methods: 2130) and total suspended solids (Photometric Method: 8006; adapted from [6]) were measured with Hach DR-890 model spectrophotometer. COD was measured with the same spectrophometer according to the Standard methods: 5220D; pH and conductivity were measured with electronic probes (Standart Methods: 2510B) [5].

Semi-permeable commercial UF and NF membranes (Alfa Laval) were used with molecular weight cut off (MWCO) of 10 kDa and 5 kDa for UF. The UF 10 kDa membrane (commercial name AlfaLaval ETNA10 PP) is made of composite fluoro polymer material, and UF 5 kDa membrane (commercial name AlfaLaval GR90PP) is made of polyether sulfone material. NF membrane is a thin film composite.

Wastewater was forced to pass through these filters with the help of a high-pressure pump, and the membrane retained an expected portion of the substances in the wastewater. The properties of the permeate water passing to the other side were analyzed and determined. The resulting water quality values were evaluated with relevant parameters and compared by checking their compliance with the literature and manufacturer's guideline values.

Table 1. Limit values for cooling tower waters

Parameter	Unit	Value	Reference
Chemical oxygen demand (COD)	mg/L	75	[7]
Total suspended solids (TSS)	mg/L	25 100	[8] [7]
Copper	mg/L	0.5 0.1	[9] [10]
pH		7.0 – 9.0 6.8 – 7.9 6.0 – 9.0 7.8 – 8.4 7.1	[8] [11] [9] [10] [12]
Conductivity	µS/cm	2000 2300	[8] [11]
Chloride	mg/L	200 528 500 471	[8] [11] [9] [12]
Chlorine	mg/L	1	[8]
Total hardness	mg/L	50 - 600 147 900 256 6250	[8] [11] [10] [12] [7]
Alkalinity	mg/L	500 200 - 250	[8] [10]
Silica	mg/L	150 150 29	[8] [10] [12]
Sulphate	mg/L	300 1980	[11] [12]
Sodium	mg/L	310	[11]
Total organic carbon (TOC)	mg/L	5 11	[11] [12]
Phosphate	mg/L	8 2	[11] [12]

Table 2. Wastewater characteristics

Parameter	Value	
	Feed for UF	Feed for NF
COD (mg/L)	1110	254
pH	5.8	8.6
Conductivity (µS/cm)	770	540
Total suspended solids (mg/L)	152	32
Turbidity (FAU)	207	78
Total hardness (mg/L $CaCO_3$)	110	750

In the study, pressurized membrane mechanism and membrane plates were used (Figure 1). For this purpose, a pre-prepared combination of Alfa Laval brand LabStak M20 model pressurized water filtration mechanism and membrane holder were prepared. The membrane to be tested was placed in the feed system and ultrapure water was passed under 2 bar pressure for the UF membrane and 4 bar pressure for the NF membrane. In the study, the temperature was kept under control and the study was carried out at 20ºC. Every thirty minutes, the flux was measured and recorded by holding a stopwatch to calculate how many seconds it took to fill the 50 mL volumetric cylinder. Then, the wastewater was passed, and the fluxes were measured in the same period; at the same time, 50 mL samples were taken from the permeate water and feed water. These procedures are set as 2 hours each. After the wastewater passage, ultrapure water flow is started for 2 hours, and flux measurements are recorded at 30-minute intervals using the same method. Then, the membranes were removed from the system and mechanically cleaned and reinserted into the system. Pure water flow tests were conducted again to see the benefit of mechanical cleaning. After mechanical cleaning, pH was adjusted to 10.50 by adding 1% caustic solution into pure water and chemical cleaning was carried out by passing this water. After chemical cleaning, pure water was passed again, and the fluxes were recorded.

Figure 1. Membrane filtration system

RESULTS and DISCUSSION

As seen from Table 3, TSS and turbidity were completely removed, however COD and conductivity rejections were 29-65% and 0-2%, respectively. In addition, hardness was not rejected, as may be expected. It was revealed that none of the processes could meet the COD criteria of 75 mg/L for cooling towers. In addition, NF could not meet the total hardness criteria of 130 mg/L (CaCO3). However, it should be noted that the raw wastewater taken from the plant was not identical for UF and NF experiments, and the composition was much more polluted for COD in the case of UF tests and total hardness in the case of NF tests. So, there is a need to conduct further tests with another wastewater sample that would be identical for all cases.

In a different study, electrocoagulation, chemical coagulation and adsorption were applied for COD removal from beverage industry wastewater [13]. It was determined that COD removal rates were 42% with the electro-coagulation technique, while 23% removal was achieved when the chemical coagulation technique was used. On the contrary, the COD removal performance was much higher in this study; with a rate of 64-65% in the UF.

The permeate water quality obtained by the membranes was compared with the relevant criteria, where the quality criteria published by the Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7] and the cooling tower manufacturer (Baltimore Air Coil Company [8]) are quite different (Table 3). The COD limit value of 75 mg/L reported in the Communiqué could not be met. Additionally, the pH value of 5.8 seen in the UF permeate was below the range specified by the tower manufacturer.

No limit value is given for conductivity in the Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7], but the conductivity of wastewater was below the value determined by the tower manufacturer (2000 uS/cm). TSS limit value, which is 100 mg/L in the Communiqué and 25 mg/L in the tower manufacturer, was met by all three membranes tested. No criterion for turbidity is reported, and it was measured as zero in the recovered water. For total hardness, a limit value of 6250 mg/L was specified in the Communiqué and 50-600 mg/L was specified by the tower manufacturer. Since quite different contents were observed in the wastewater samples, while the limit values were achieved with UF membranes, the NF effluent hardness value remained above the tower manufacturer's criterion.

Flux decline was in the range of 10- 20% (Table 4). As the flux decline was low, cleaning had little impact on flux recovery. The mechanical cleaning and chemical cleaning with NaOH provided flux recovery of 92-95% for UF and 134% for NF.

In literature no study on the recovery of soft drink wastewater via membrane processes as a cooling water make up was available. One relevant study investigated the water conservation and reuse opportunities in a soft drink/beverage manufacturing company [14]. The authors carried out water use analysis and benchmarking in order to figure out the areas and processes with significant water saving potential. The evaluations revealed a reduction of the total specific cooling water demand of the company from 14.4 to 1.2 m^3/m^3 product, corresponding to 91.8%.

In another study performed at an oil and gas facility [11], the applicability of municipal reclaimed water as an alternative to groundwater for an industrial cooling system was investigated and the treated wastewater effluent was utilized as make up water for a 4.2 MW cooling tower. The use of reclaimed water was found to be economically viable with 27% reduction in water consumption. It is also reported that reclaimed water is becoming standard for new power plant construction as well as a viable alternative makeup water source for existing facilities that plan to expand production [12]. Regarding the high water consumption of beverage industry, more case studies are needed to widely implement water reuse applications and reduce the water footprint of soft drinks and beverages.

Table 3. Comparison of criteria for cooling towers with the rejection performance of UF and NF membranes

	Parameter					
	COD (mg/L)	pH	Conductivity (µS/cm)	TSS (mg/L)	Turbidity (FAU)	Total hardness (mg/L $CaCO_3$)
Criteria for cooling towers						
National Regulation[a]	75	-	-	100	-	6250
Cooling Tower Producer[b]	-	7 - 9	2000	25	-	50 - 600
Membrane Performance						
Feed						
UF (10 kDa)	796	5.7	572	121	162	95
UF (5 kDa)	718	5.8	572	121	162	95
NF	207	8.6	520	30	80	750
Permeate						
UF (10 kDa)	286	5.7	560	0	0	95
UF (5 kDa)	255	5.6	570	0	0	95
NF	147	8.6	530	0	0	750
Rejection (%)						
UF (10 kDa)	64	-	2	100	100	0
UF (5 kDa)	65	-	0	100	100	0
NF	29	-	0	100	100	0

[a]: Amended Technical Procedures Communique of National Regulation for Wastewater Treatment Plants [7], Table E.7.21. Water Quality Recommended for Cooling Towers bBAC (Baltimore Aircoil Company) criteria [8]

Table 4. Flux decline and recovery for membranes

Process	Flux (L/m^2/h)			
	Clean water (initial)	Wastewater	Clean water (after mechanical cleaning)	Clean water (after chemical cleaning)
UF (10 kDa)	52.6	47.2	48.5	50.0
UF (5 kDa)	61.0	51.0	53.8	56.1
NF	116.3	92.6	156.3	156.3
Flux Decline (%)				
UF (10 kDa)		10		
UF (5 kDa)		16		
NF		20		
Flux Recovery (%)				
UF (10 kDa)			92	95
UF (5 kDa)			88	92
NF			134	134

CONCLUSION

Although total suspended solids and turbidity were completely removed with UF and NF, the removal of COD and dissolved substances was not fully achieved. Total hardness could not be eliminated. Therefore, it will be necessary to apply additional treatment to meet the COD and total hardness limit values. It is highly probable that required quality value will be achieved by applying single stage reverse osmosis (RO) or double stage NF.

The fact that solids are completely removed, and the hardness value is at a medium level makes it possible to use the reclaimed water in the systems by passing it through a resin before feeding it to the cooling tower. However, since the COD value has not been reduced to the 75 mg/L limit value, it is not recommended to feed the reclaimed water to the cooling tower directly. The organic pollution in the feed water can cause growth of microbiological organisms in the cooling tower. Additional biocide use may be required. However, feedwater organic load always poses a risk.

The fact that the treatment plant is at the project stage for this sample facility is promising in terms of the applicability of the results of the study. It allows the water resulting from pre-treatment to be passed through the membrane and fed into cooling systems quickly and effectively, or even fed into closed circuits and steam boilers.

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Research Paper / Araştırma Makalesi

Effects of Red Grape (*Vitis Vinifera* L.) Pomace Powder on Physicochemical and Textural Properties of Sucuk

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ABSTRACT

This study aimed to evaluate the effect of grape pomace powder as a natural antioxidant on the quality characteristics of sucuk samples. Grape pomace powder was added to the sucuk doughs at various concentrations (0, 1, 2, and 3%), and sucuk fermentation was carried out under controlled conditions. The study investigated the effects of grape pomace powder on the chemical composition, total phenolic content, antioxidant activity, texture profile, and color characteristics of the sucuk samples. Results showed a significant impact (P<0.05) of grape pomace powder incorporation on the fat, protein, pH, color, total phenolic content, and antioxidant activity of the samples. All color values and pH levels decreased as the amount of grape pomace powder increased. In contrast, total phenolic content and antioxidant activity values increased in direct proportion to the amount of grape pomace powder. According to these results, grape pomace powder has the potential to be used as a natural antioxidant in sucuk production.

Keywords: Sucuk, Grape pomace, Waste, Value added product, Natural antioxidant

Kırmızı Üzüm (*Vitis Vinifera* L.) Posası Tozunun Sucuğun Fizikokimyasal ve Tekstürel Özellikleri Üzerine Etkisi

ÖZ

Bu çalışmada doğal bir antioksidan olan üzüm posası tozunun sucuk örneklerinin kalite özelliklerine etkisinin değerlendirilmesi amaçlanmıştır. Bu amaçla üzüm posası tozu sucuk hamurlarına çeşitli konsantrasyonlarda (%0, 1, 2 ve 3) eklenmiş ve sucuk fermantasyonu kontrollü koşullar altında gerçekleştirilmiştir. Üzüm posası tozunun sucuk örneklerinin kimyasal bileşimi, toplam fenolik madde miktarı, antioksidan aktivite, tekstür ve renk analizleri üzerindeki etkisi araştırılmıştır. Sonuçlar üzüm posası tozu ilavesinin örneklerin yağ, protein, pH, renk, toplam fenolik madde miktarı ve antioksidan aktivitesi üzerinde önemli bir etkisinin olduğunu göstermiştir (P<0.05). Üzüm çekirdeği tozu miktarı arttıkça tüm renk değerleri ve pH azalmıştır. Buna karşılık toplam fenolik madde miktarı ve antioksidan aktivite değerleri üzüm çekirdeği tozu miktarıyla doğru orantılı olarak artmıştır. Çalışmada elde edilen sonuçlara göre, üzüm çekirdeği tozunun sucuk üretiminde doğal bir antioksidan olarak kullanım potansiyeline sahip olduğu düşünülmektedir.

Anahtar Kelimeler: Sucuk, Üzüm posası, Atık, Katma değerli ürün, Doğal antioksidan

INTRODUCTION

In recent years, concerns about the consumption of certain foods have escalated due to studies exploring the connections between dietary habits and health issues [1]. The necessity to address consumers' concerns and to make processed foods more beneficial to health has led to the emergence of innovative practices in the food industry [2, 3]. Among these innovative practices are enhancing the nutritional value of food, strengthening dietary fiber content, and replacing synthetic additives with natural ingredients in production [2]. In this context, research focusing on the utilization of natural plant sources with high phenolic compound content in food formulations has gained prominence in the literature [4-7]. Due to their high content of bioactive compounds and their positive effects on health, grape pomace, which is among these plant sources, can be utilized as a functional ingredient in today's context [8, 9]. Grape pomace, consisting of skins, pulp, and seeds, can account for up to 20% of the weight of processed grapes [10]. The generated grape pomace poses a significant disposal challenge for the viticulture industry. However, due to its phenolic compounds, it attracts considerable attention in the literature as it provides an economic recycling output [11, 12].

Fermented meat products are popular worldwide and sucuk is one of the most consumed fermented meat products in Türkiye [13, 14]. However, meat products are highly susceptible to spoilage due to their rich nutrient content and perishable nature. Therefore, if they are not properly handled and preserved, they can deteriorate and pose a potential public health risks [15]. Recently, studies have focused on extending the shelf life of sucuk production by using nutrient-preserving and enhancing additives while maintaining quality [16, 17]. The bioactive composition of grape pomace includes anthocyanins, flavanols, and phenolic acids, which can extend the shelf life of meat products by inhibiting microbial growth and delaying oxidative processes responsible for the deterioration of sensory and nutritional quality [18]. Furthermore, effective utilization of grape pomace is reported not only to expand relevant industries but also to increase economic benefits by reducing environmental pollution [19].

Upon reviewing the literature, it has been observed that there are a limited number of studies investigating the use of grape pomace powder in the food industry. Additionally, no studies have been found to assess the effects of grape pomace powder on quality characteristics of sucuk. Therefore, the aim of this study was to determine the effect of grape pomace, which is rich in dietary fiber, minerals, and polyphenols (such as proanthocyanidins, flavonoids, phenolic acids, and stilbens) as a natural source of antioxidants on physiochemical and textural properties of sucuk and to present an innovative approach in terms of waste utilization and environmental sensitivity.

MATERIALS and METHODS

Materials

The grape pomace (*Vitis vinifera* L. ssp. *vinifera*) was obtained from the Manisa Viticulture Research Institute (Manisa, Türkiye). Fresh lean beef, beef tail fat, spices and natural cases (D:38 mm, air dired bovine small intestine) used in sucuk production were obtained from local market in Manisa, Türkiye. The other chemicals were supplied from Sigma Aldrich, St. Louis, USA.

Production of Grape Pomace Powder

The grape pomace was subjected to a drying process involving washing and cleaning, followed by drying in a tray dryer at 50°C with an air velocity of 1.5 m/s until it reached a moisture content of 16-18%. The dried pomace was pulverized into powder form by grinding it three times for 15 seconds at 5000 rpm using a blade grinder (Retsch, GM200, Germany) to increase the surface area. The powdered pomace was then sieved using a 100-micron mesh sieve, and the particle sizes were standardized.

Sucuk Formulation and Preparation

Four different groups of sucuk production were conducted to determine the chemical composition, total phenolic content, antioxidant activity, texture profile and color values of sucuks with varying levels of added grape pomace powder. Preliminary experiments were conducted to determine the appropriate grape pomace powder concentration for preserving and enhancing quality characteristics of sucuk. In the previous studies, it was investigated that the addition of grape by-products in the range of 0.75-3.0% had potential usage by enhancing the oxidative and microbial quality of meat products without negatively affecting sensorial quality [20–22]. Carrapiso et al. [23] concluded that 3% grape pomace with a detrimental effect on some sensory characteristics of dry-cured sausages. In addition, Sanchez-Alonso et al. [24] evaluated that fish samples with 4% of grape by-products were not well accepted by semi-trained panelists. So in this study, the grape pomace powder was used up to 3% concentration. The experimental groups consisted of sucuk samples without added grape pomace powder (Control), sucuk samples containing 1% grape pomace powder (GPP1), sucuk samples containing 2% grape pomace powder (GPP2), and sucuk samples containing 3% grape pomace powder (GPP3). The formulation used in sucuk production are presented in Table 1.

The sucuk production flow chart is shown in Figure 1. Fresh lean beef (*Musculus semitendinosus*) as boneless round and tallow fat was purchased from a commercial manufacturer and refrigerated at 4°C during preparation. The production of sucuk was carried out in the Manisa Celal Bayar University Food Engineering Department Meat Science and Technology Laboratory according to the traditional method by Kayaardı and Gök [25]. Other ingredients were supplied from local markets in Manisa, Türkiye. Each sample group was weighed to contain 85% beef meat and 15% beef tallow fat. The other ingredients were added per kg of fresh lean beef and tallow fat mixture, as shown in Table 1. The freshly obtained meat was cut into small pieces and mixed with spices and grape pomace powder according to the experimental design. All the sucuk batches were refrigerated at 4°C overnight. The sucuk mixtures were ground in a grinding machine through a 3-mm grid (Tefal, France) with beef tallow fat and stuffed into air-dried natural casings (D:38 mm) from bovine small intestine. The casings were soaked in a 5% lactic acid solution for 20 minutes before filling. The sucuks were fermented in a controlled cabinet

(Nüve, Turkey) and ripened under the following conditions: 0-3 days at 90% RH, 22°C, and 1.0 m/s air velocity; 4-7 days at 85% RH, 20°C, and 0.5 m/s air velocity; and 7-10 days 80% RH, 18°C, and 0.5 m/s air velocity. During fermentation and ripening, pH monitoring was conducted on sucuk samples. The fermentation and ripening were terminated when the pH reached 4.8. After ripening, all samples were subjected to physicochemical ve textural analysis.

Table 1. Formulations of sucuks

Ingredients	Control*	GPP1	GPP2	GPP3
Beef (g)	850	850	850	850
Beef tallow fat (g)	150	150	150	150
Salt (g)	20	20	20	20
Sugar (g)	4	4	4	4
Garlic (g)	11	11	11	11
Red pepper (g)	12	12	12	12
Cumin (g)	10	10	10	10
Black pepper (g)	8	8	8	8
Allspice (g)	2.5	2.5	2.5	2.5
$NaNO_2$ (ppm)	100	100	100	100
$NaNO_3$ (ppm)	150	150	150	150
Grape pomace powder (g)	0	10	20	30

*Control: sucuk samples without added grape pomace powder (control); GPP1: sucuk samples containing 1% grape pomace powder; GPP2: sucuk samples containing 2% grape pomace powder; GPP3: sucuk samples containing 3% grape pomace powder

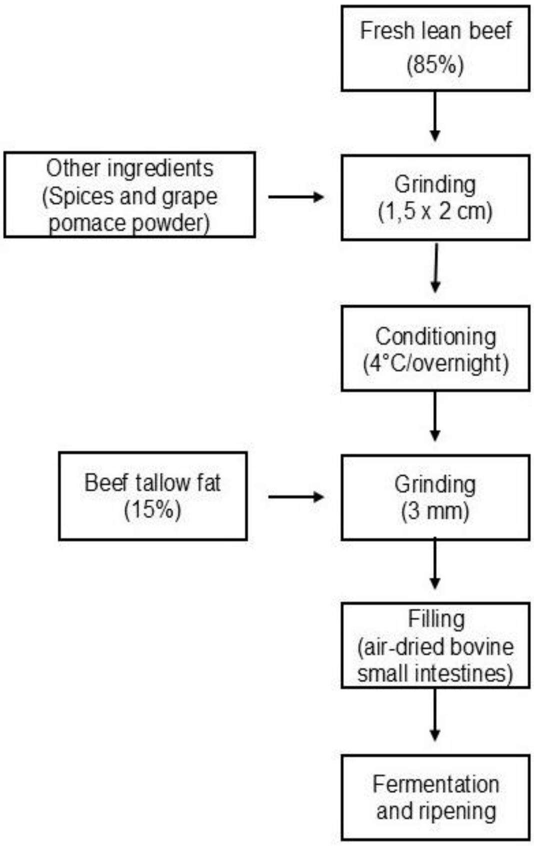


Figure 1. Sucuk production flow chart

Proximate Composition

The sucuk samples were analyzed for moisture (method 934.01), ash (method 942.05), fat (920.39) and protein (method 968.06) contents according to AOAC (2007) standards [26].

pH

The pH values of the samples were determined using a digital pH meter model pH 730 (WTW, Weilheim, Germany) and standardized with appropriate buffers. Measurements were taken from five different regions of the samples. The pH meter probe was immersed in the sample and allowed to stabilize until the value on the display remained constant. The average of five measurements was recorded as the pH value [27].

Color

The color values of the samples (CIE *L*, a*, b**) were determined using a colorimeter Minolta Chromameter CR-5 model (Konica-Minolta Camera Co. Ltd., Osaka, Japan). Evaluation was conducted based on the *L** (darkness-lightness), *a** (redness-greenness), and *b** (yellowness-blueness) color parameters using the CIELAB system. The samples were unpacked and allowed to rest for 10 minutes before color measurements were taken. Five readings were taken from five different regions for each sample [25]. The total color differences in color reading values were calculated as reported by Savanovic et al. [28]. The color values of the control group without added grape pomace powder were used as the reference for calculating ΔE^* in the sample groups containing grape pomace powder at various concentrations.

Total Phenolic Content and Antioxidant Activity

Extractions Procedure for Total Phenolic Content and Antioxidant Activity Assays

Samples were prepared following a modification of the method outlined by Pritchard et al. [29]. Five grams of sucuk samples were taken, and then 50 mL of distilled water was added to the samples, which were subsequently homogenized using an Ultraturrax

(WiseThis HG-15D, Daihan Scientific Co., Seoul, Korea). After that, centrifugation was performed at 4100 rpm at 20°C to transfer the upper phase to a volumetric flask. The same process was repeated twice for the residue. The collected upper phases were combined and brought up to 100 mL with distilled water. The upper phase was filtered and kept at -18°C until analysis.

Total Phenolic Content

The total phenolic content of the samples was determined according to the Folin-Ciocalteu method, modified by Kucuker et al. [30] based on the method developed by Singleton & Rossi [31]. One milliliter of the sample extract obtained through the extraction process was mixed with 0.5 mL of 10% Folin-Ciocalteu's phenol solution and vortexed for 15 seconds. The mixture was then left in the dark at room temperature for 5 minutes. After this period, 1.5 mL of 7.5% Na_2CO_3 solution was added to the mixture, and the sample solution was left in the dark at room temperature for an additional 60 minutes. Subsequently, the absorbance of the resulting color was measured at 760 nm using a Multiskan Go Microplate Spectrophotometer (Thermo Scientific, USA). The results were calculated based on the gallic acid standard curve, and the total phenolic content was determined by substituting the absorbance values obtained from the gallic acid standard curve into the linear regression equation. The total phenolic content is expressed as gallic acid equivalent (GAE) using the gallic acid (0.1 mg/mL) calibration curve.

Antioxidant Activity

The DPPH radical scavenging activity of the sucuk samples was determined according to the method described by Brand-Williams et al. [32] and Singh et al. [33]. Briefly, 100 µL of sample was mixed with 2 mL of 0.1 mM DPPH (1,1-diphenyl-2-picrylhydrazyl) solution in tubes. The tubes were thoroughly mixed and left in the dark at room temperature for 30 minutes. After incubation, the absorbance values against the blank were read at 517 nm using a Multiskan Go Microplate Spectrophotometer (Thermo Scientific, USA), and the results were calculated using the following equation:

$$\text{Total antioxidant activity (\%)} = (1 - A_{sample}/A_{control}) \times 100$$

Where A_{sample}= is the absorbance after addition of test sample (DPPH solution with test sample) and $A_{control}$= is the absorbance of the control (DPPH• solution without test sample).

Texture Profile Analysis

Texture profile analysis (TPA) of samples was conducted using a TA-XT Plus Texture Analyzer (Stable Micro Systems, England). Samples were sliced to a thickness of 0.5 mm and analyzed at room temperature. A 5 kg load cell was used in the experiments and the samples were compressed to 50% of their original height using a cylindrical probe with a diameter of 38 mm. The sample was positioned under the probe, which moved downwards at a constant speed of 2.0 mm.s^{-1} during the pre-test and test phases, and 5.0 mm.s^{-1} during the post-test phase. A 5-second interval was provided between the two compression cycles. The TPA parameters, including hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness were determined following the method described by Mochizuki [34] The measurements of each sample were replicated at least six times. All textural analyses were performed using Texture Exponent software version 4.0.9.0 (Stable Microsystems Ltd., Surrey, England).

Statistical Analyses and Experimental Design

The overall procedure carried out for sucuk manufacture was replicated twice by producing two separate batches on different days. Total of four independent formulations (Control, GPP1, GPP2, GPP3) were created within one replication. For each replicated sample, all experiments were performed three times. The experimental data were statistically evaluated by using the SPSS Version 24.0. One-way analysis of variance (ANOVA) was used to compare the effects of different treatments between groups. Means were compared at 5% significance level ($P<0.05$) by Duncan's multiple range test and the data were reported as the means ± standard errors.

RESULTS and DISCUSSION

Proximate Composition

The proximate composition (moisture, ash, fat and protein) of sucuk samples containing red grape pomace powder is presented in Table 2. The moisture content of the control group was found to be 38.79, but the others varied between 36.32% and 41.02%. The significant differences in moisture content were determined between the GPP1 and GPP2 samples ($P<0.05$), which did not differ from the control group ($P>0.05$). The total ash, fat and protein content of the samples was determined to be between 3.42-3.50%; 21.79-24.34% and 19.17-22.04%, respectively. The effects of grape pomace powder on fat and protein contents of sucuk were found to be significant ($P<0.05$). The fat content was similar in the control, GPP1 and GPP3, while GPP2 samples had significantly lower fat content compared to the control group ($P<0.05$). The incorporation of grape pomace powder also led to significant changes in the protein contents of samples. All treatments had significantly lower protein content than control group ($P<0.05$). The Turkish Food Codex (2019) specifies that sucuk should contain at least 16% total meat protein by weight, with the moisture to protein ratio not exceeding 2.5, and the fat to protein ratio also below 2.5 [35]. Assessing these regulations, it was found that all samples had a protein content exceeding 16%, with an average moisture-to-protein ratio of 1.97 and an average fat-to-protein ratio of 1.16. Therefore, our results indicated that all samples complied with the criteria outlined by those standards.

Table 2. Proximate composition and pH values of sucuk samples

Sample group*	Moisture (%)**	Ash (%)	Fat (%)	Protein (%)	pH
Control	38.79±0.77[ab***]	3.49±0.09	24.10±0.77[a]	22.04±0.05[a]	4.94±0.006[a]
GPP1	41.02±2.50[a]	3.42±0.04	24.34±0.83[a]	19.17±0.03[c]	4.75±0.03[b]
GPP2	36.32±0.89[b]	3.50±0.31	21.79±0.49[b]	19.41±0.05[b]	4.81±0.03[b]
GPP3	40.69±1.67[ab]	3.41±0.09	22.19±1.01[ab]	19.33±0.01[b]	4.79±0.005[b]

*Control: sucuk samples without grape pomace powder addition; GPP1: sucuk samples fortified with 1% grape pomace powder; GPP2: sucuk samples fortified with 2% grape pomace powder; GPP3: sucuk samples fortified with 3% grape pomace powder; **The values were expressed as mean ± SD.***a-d: different letters within a same column indicate the effect of treatment and differ significantly (P<0.05).

pH

The mean pH values of sucuk samples incorporated with varying levels of grape pomace powder are shown in Table 2. The pH values of the samples ranged between 4.75-4.94. The incorporation of grape pomace powder resulted in significant changes in the pH values of sucuk samples (P<0.05). The control group exhibited the highest pH value compared to the other tested groups. The pH values of the samples containing grape pomace powder were significantly lower than the control group (P<0.05). This result might be due to the acidic and polyphenolic compounds present in grape pomace powder. Moreover, the pH values of all treatments were compliant with The Turkish Food Codex (2019) of a maximum 5.4 value of below for sucuk. Similarly, the pH values of frankfurters reduced from 6.12 to 5.97 with the addition of starch-sodium caseinate and grape seed flour [35]. On the contrary, Kurt [21]reported that the pH values of sucuk samples increased with the inclusion of grape seed extract during ripening and storage. These variations may be attributed to the distinct characteristics of the ingredients added to the formulation and the type of the product.

Instrumental Color Analysis

Color is a crucial visual attribute through which consumers often assess the quality and desirability of a product. Table 3 illustrates the instrumental color parameters (*L**, *a**, *b**) of sucuk samples. A significant reduction in *L**, *a**, *b** values was observed upon the addition of grape pomace powder in sucuk samples (P<0.05). The incorporation of grape pomace powder resulted in a darkening of the samples, with a greater browning degree observed at higher concentrations of grape pomace powder. Similarly, both the *a** and *b** values of the samples decreased with increasing amounts of grape pomace powder. This decrease in the color values may be due to the masking of the product's natural color caused by the addition of grape pomace powder. Riazi et al. [22] also reported similar decreases in *L**, *a**, parameters for beef sausage samples fortified with grape pomace powder at various concentration (1% and 2%) compared to control group. The decreases in *L** values can be attributed to the antioxidant effect of grape pomace powder, which is rich in variety of phenolic compounds that have free radical scavenging properties [36].

Table 3. Color values of sucuk samples

Sample group[+]	*L**[++]	*a**	*b**	*ΔE**
Control	51.78±0.26[a+++]	16.55±0.55[a]	23.63±0.27[a]	0
GPP1	50.64±1.07[ab]	15.36±0.24[b]	20.46±0.62[b]	3.60±1.07[b]
GPP2	47.00±0.58[c]	13.57±0.16[c]	18.97±0.45[c]	7.32±0.38[a]
GPP3	49.37±0.73[b]	12.89±0.19[d]	18.96±0.08[c]	6.41±0.23[a]

[+]Control: sucuk samples without grape pomace powder addition; GPP1: sucuk samples fortified with 1% grape pomace powder; GPP2: sucuk samples fortified with 2% grape pomace powder; GPP3: sucuk samples fortified with 3% grape pomace powder; [++]The values were expressed as mean ± SD. [+++]a-d: different letters within a same column indicate the effect of treatment and differ significantly (P<0.05).

The total color differences (*ΔE**) is typically considered an indicator of differences noticeable to the human eye. The findings indicated that the use of grape pomace powder at concentration 2% and 3% in sucuk formulation significantly impacted total color differences compared to its use at a concentration of 1% (P<0.05). According to the International Lighting Commission (CIE), a total color difference between 0 and 2 is undetectable and a difference between 2 and 3.5 can be recognized by an inexperienced observer, while a value exceeding 3.5 indicates a noticeable color deviation for the observer (P<0.05) [28]. Thus, in the present study the total color differences of all samples were significantly recognizable by the observer (P<0.05). The smallest color changes were determined in the GPP1 group while the largest color changes were observed in GPP2 group. The results suggest that sucuk samples containing grape pomace powder were more dissimilar in color, compared to control group. It could be due to anthocyanins present in the red grape pomace [37].

Texture Profile Analysis

The texture profile results of the sample groups are presented in Table 4. The addition of grape pomace powder did not affect the hardness, adhesiveness, springiness, gumminess, or chewiness values of the samples statistically (P>0.05).

The hardness values of samples increased and the chewiness values of the samples decreased with the addition of grape pomace powder compared to the control group, but these changes were not statistically different (P>0.05). Grape pomace powder had a high dry matter content, so this may be the reason for the increased hardness values [38]. Similarly, Alencar et al. [39] found that the addition of grape skin flour to beef burgers increased the hardness values of the samples compared to the control group (P<0.05). Also, Pereira et al. [38] had reported that addition of grape pomace to hamburger patties increased the hardness values compared to control samples (P<0.05). They concluded that the dietary fiber content of grape pomace powder had contributed to the increase of the hardness values.

Table 4. Texture profile analyze values of sucuk samples

Sample group*	Hardness (N)**	Adhesiveness (N.s)	Springiness	Cohesiveness	Gumminess	Chewiness
Control	95.93±15.77	-0.72±0.26	0.76±0.08^{a***}	0.68±0.10	66.60±20.3	51.46±19.32
GPP1	138.67±13.91	-1.14±0.34	0.66±0.11^{ab}	0.56±0.09	76.37±5.97	50.89±10.94
GPP2	103.50±58.62	-0.76±0.15	0.55±0.07^{b}	0.64±0.02	66.74±39.78	38.57±27.57
GPP3	107.89±12.92	-0.77±0.01	0.53±0.04^{b}	0.62±0.05	66.79±8.44	35.38±2.14

*Control: sucuk samples without grape pomace powder addition; GPP1: sucuk samples fortified with 1% grape pomace powder; GPP2: sucuk samples fortified with 2% grape pomace powder; GPP3: sucuk samples fortified with 3% grape pomace powder; **The values were expressed as mean ± SD.; ***a-d: different letters within a same column indicate the effect of treatment and differ significantly (P<0.05).

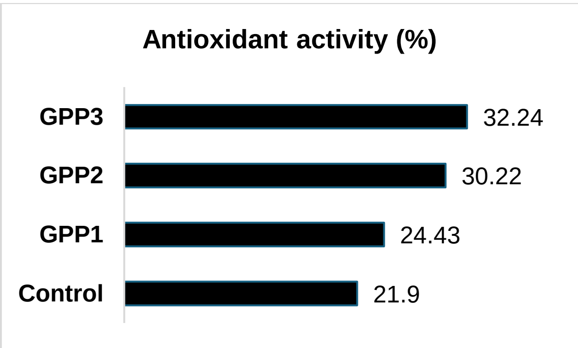
Total Phenolic Content and Antioxidant Activity

As can be seen in Table 5, the total phenolic content of the samples was found to be between 13.72-23.15 mg/100 g dry matter. All sample groups had higher phenolic content than control group. It is clear from the results that as the level of grape pomace powder increased, the phenolic content increased. The statistical differences between the sample groups were significant (P < 0.05). The antioxidant activities of the samples were found to be between 21.90-32.24 %. All sample groups fortified with grape pomace powder had higher antioxidant activities than the control group. GPP3 samples had the highest antioxidant activity, but the difference between GPP3 and GPP2, and also the difference between control and GPP1 samples, was not statistically different (P>0.05).

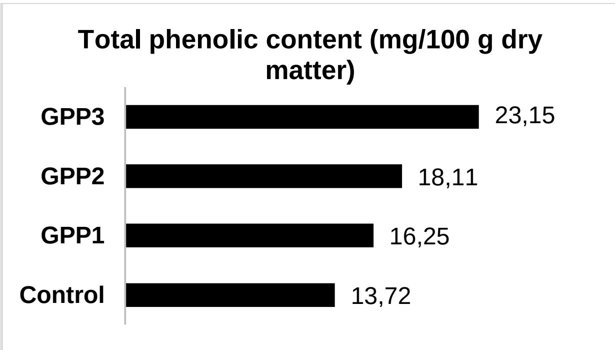
Table 5. Total phenolic content and antioxidant activity of sucuk samples

Sample group*	Total phenolic content (mg/100g dry matter)**	Antioxidant activity (%)
Control	13,72±0.35^{d***}	21.90±1.44^{b}
GPP1	16.25±0.78^{c}	24.43±0.36^{b}
GPP2	18.11±0.09^{b}	30.22±1.83^{a}
GPP3	23.15±0.67^{a}	32.24±2.1^{a}

*Control: Sucuk samples without grape pomace powder addition; GPP1: Sucuk samples fortified with 1% grape pomace powder; GPP2: Sucuk samples fortified with 2% grape pomace powder; GPP3: Sucuk samples fortified with 3% grape pomace powder; **The values were expressed as mean±SD.; ***a-d: Different letters within a same column indicate the effect of treatment and differ significantly (P<0.05).



(a)



(b)

Figure 2. (a) Antioxidant activity(%), (b) Total phenolic content of the sucuk samples (mg/100 g dry matter) (Control: sucuk samples without grape pomace powder addition; GPP1: sucuk samples fortified with 1% grape pomace powder; GPP2: sucuk samples fortified with 2% grape pomace powder; GPP3: sucuk samples fortified with 3% grape pomace powder)

As mentioned in several studies, grape and grape by-products with high levels of flavanols, phenolic acids, anthocyanins and tannins had antioxidant and antimicrobial effects on meat and meat products [18, 21, 40–52]. It is thought that the increase in grape pomace powder addition rate increases antioxidant activity and phenolic content in direct proportion [22]. In this study, the antioxidant activity of grape pomace powder was found to be 98.30±0.06 (%). This result is in agreement with Zhu et al. [53] who found the antioxidant activity of wine grape pomace 96.0 % and lower than the DPPH scavenging activity of grape pomace powder investigated by Hayta et al. [54]. In the study conducted by Amin & Edris [55], it was found that incorporation of minced meat with different levels of grape seed extract (50, 200 and 1000 ppm) showed increasing antioxidant activity (%) with the increased grape seed extract level. Carrapiso et al. [23] noted that the grape pomace added in the levels of 0.5% and 3% provided 3.83 and 22.9 mg phenols 100 g−1 of fresh batter, respectively. Riazi et al. [22] found total phenol content of dry cured sausages between 62-74 mg gallic acid/100 g sample. It was noted that he lowest levels were for control samples, while the highest contents were for grape pomace-added (1% and 2%, w/w) ones. The values were higher than the phenolic content of the samples in our study but the increase in phenolic content by the addition rate of grape pomace powder is in agreement with this study.

CONCLUSION

In conclusion, the results of the present study revealed that incorporating grape pomace powder is a viable option as a natural additive in sucuk, improving total phenolic content and antioxidant activity while maintaining quality characteristics in terms of chemical composition and pH without negatively impacting textural properties. The addition of grape pomace powder resulted in a significant increase in the total phenolic and antioxidant activities of the samples, leading to the conclusion that these types of foods may have nutritionally beneficial properties (P<0.05). In addition, GPP-treated samples showed significantly lower pH and color values than those of the control (P<0.05). However, grape pomace powder addition had a noticeable effect on sucuk color as perceived by the human eye. The decrease in the color values of the samples could be due to the darker color of the grape pomace powder ingredient. Based on the promising results, especially in the nutritional aspects, future research could focus on the studying consumer acceptance as well as microbiological and oxidative changes during storage.

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Research Paper / Araştırma Makalesi

Advanced Statistical Optimization for Enhanced Medium-Chain Fatty Acid Production

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ABSTRACT

In recent years, the development of feed ingredients with natural additives has gained significant importance in increasing the health and quality of animal products, as well as in promoting weight gain in animals. Since *Salmonella* infection is a significant disease that transmits from animals to humans, the inhibition of Salmonella species can be achieved particularly through the improvement of gastrointestinal metabolism in chickens. At this point, the effectiveness of using MCFA (Medium Chain Fatty Acids) as a feed additive has been proven. MCFA are composed of a mixture of various fatty acids, including acetic acid, butyric acid, hexanoic acid, etc. Highest portion of MCFA are hexanoic acid. Besides feed additives hexanoic acid play a crucial role as primary resources in various industries, including the chemical, food, agricultural, and biofuel sectors. It is typically obtained from petrochemical-based solutions but there has been a growing focus on biotechnological production and natural sources in recent years. One of the mostly known bioprocess to produce MCFA is chain elongation (conversion of acetate and ethanol into MCFA by β oxidation reaction) by *Clostridium kluyveri.* However, as in most biotechnological processes, there are low yields and high costs in these reactions as well. In this study, Box-Behnken Design, a statistical experimental design method, was used to optimize the concentrations of acetate, ethanol (the two primary components of chain elongation reactions) and pH for MCFA production via chain elongation reactions with *Clostridium kluyveri*. Batch experiments were performed at 30°C and 37°C to also see the effect of temperature. Higher values of hexanoic acid and bacterial growth were observed at 37°C. From an economic perspective, a 14% reduction in costs has been observed with optimized components.

Keywords: Hexanoic acid, *Clostridium kluyveri*, acetate, ethanol, chain elongation reactions, Box-Behnken Design of Experiments

Orta Zincirli Yağ Asidi Üretiminin Artırılması İçin İleri İstatistiksel Optimizasyon

ÖZ

Son yıllarda, doğal katkı maddeleri içeren yem bileşenlerinin geliştirilmesi, hayvan ürünlerinin sağlığını ve kalitesini artırmanın yanı sıra hayvanlarda kilo alımını teşvik etmede önemli bir rol oynamıştır. Salmonella enfeksiyonları, hayvanlardan insanlara bulaşan önemli bir hastalık olduğundan, Salmonella türlerinin inhibe edilmesi özellikle tavukların gastrointestinal metabolizmasının iyileştirilmesiyle sağlanabilir. Bu noktada, orta zincirli yağ asitleri (MCFA) kullanımının bir yem katkı maddesi olarak etkinliği kanıtlanmıştır. MCFA, asetik asit, bütirik asit, hekzanoik asit vb. dahil olmak üzere çeşitli yağ asitlerinin karışımından oluşur. MCFA karışımının en büyük kısmını hekzanoik asit oluşturmaktadır. Yem katkı maddesi olarak kullanımının yanısıra hekzanoik asit, kimya, gıda, tarım ve biyoyakıt sektörleri de dahil olmak üzere çeşitli endüstrilerde birincil kaynak olarak önemli bir rol oynamaktadır. Son yıllarda biyoteknolojik üretim ve doğal kaynaklara giderek daha fazla odaklanılmasına rağmen, tipik olarak petrokimya bazlı çözümlerden elde edilmektedir. Ancak, çoğu biyoteknolojik süreçte olduğu gibi, bu reaksiyonlarda da düşük verim ve yüksek maliyetler söz konusudur. Bu çalışmada, *Clostridium kluyveri* ile asetat, etanol (zincir uzama reaksiyonlarının iki ana bileşeni) ve pH konsantrasyonlarını optimize etmek için istatistiksel bir deneysel tasarım yöntemi olan Box-Behnken Tasarımı kullanılmıştır. Sıcaklığın etkisini de görmek için 30°C ve 37°C'de toplu deneyler gerçekleştirilmiştir. Daha yüksek hekzanoik asit değerleri ve bakteri büyümesi 37°C'de gözlenmiştir. Ekonomik açıdan ise ortam bileşenlerinin optimizasyonu proses maliyetlerinde %14'lük bir düşüş sağlamıştır.

Anahtar Kelimeler: Hekzanoik asit, *Clostridium kluyveri*, Asetat, Etanol, Zincir uzama reaksiyonları, Box-Behnken Dizaynı

INTRODUCTION

In recent years, biotechnological production methods have gained increasing significance because to their environmentally friendly nature, utilization of waste materials, less dependence on chemicals, and ability to operate at lower temperatures [1, 2]. Carboxylate based chemical platforms are considered a promising alternative to anaerobic digestion to produce sustainable fuels and chemicals from biomass and organic waste [3].

Medium chain fatty acids, so-called MCFAs, are composed of a mixture of various fatty acids, including butyric acid, pentanoic acid, hexanoic acid, and others. MCFA play a crucial role as primary resources in various industries, including the chemical, food, agricultural, and biofuel sectors. MCFA is typically obtained from petrochemical-based solutions, although there has been a growing focus on biotechnological production and natural sources in recent years. The process of obtaining MCFA from coconut oil or goat milk is referred to as biobased manufacturing. However, this method constitutes a challenge in terms of food security. The production of MCFA through bacterial chain elongation has gained importance in recent years [4, 5]. MCFA mixture rich in hexanoic acid can be synthesized through chain elongation process using *Clostridium* species. A large portion of the MCFA produced as a result of the chain elongation reaction is composed of hexanoic acid. There are significant studies in the literature showing that when hexanoic acid is used as a feed additive in livestock, it can improve the gastrointestinal systems of animals and prevent Salmonella infections, which is a major issue [6-7]. By chain elongation reactions during anaerobic biotechnological process, volatile fatty acids (VFAs) and the source of electrons can be transferred into MCFA, which are more valuable bioproducts [8]. Conversion of short chain acids and alcohols to MCFAs with ethanol which acts as electron donor is performed by chain elongation reaction microorganisms (i.e., *Clostridium kluyveri*) using the reverse β-oxidation pathway. The pathway includes oxidation of ethanol to form acetate for every five chain elongation reactions (Equation 1) [9].

Reverse β-oxidation reaction:

$$5\ C_xH_{2x}^{-1}\ O_2^{-}+6\ C_2H_6O \rightarrow 5C_x+2H_{2x}+3O_2^{-}+C_2H_3O_2^{-}+4H_2O+H^{+}+2H_2 \qquad (1)$$

MCFA can be produced by hydrolysis and acidogenesis of organic wastes. The electron carriers for MCFA production such as ethanol, hydrogen [10], methanol [11] and lactic acid [12] can also be generated from organic wastes via biochemical and thermochemical conversion of organic wastes. The most significant disadvantages of chain elongation reactions are high process costs and low yields.

Given the low yields of chain elongation reactions and the high cost of process inputs, it is necessary to optimize production conditions to both increase production and decrease cost. Experimental design methodologies are very useful for optimization processes. Experimental design is a systematic process that involves the careful selection and control of significant components using various designs to acquire crucial answers. This approach is typically followed by statistical analysis [13]. A Box-Behnken design (BBD) is a type of fractional factorial design consisting of three levels. It was established by Box and Behnken and is used to analyze the response surface within a specific experimental zone. It has many advantages over factorial design such as lower experiment needs. The design is a hybrid of a two-level factorial design and an incomplete block design. In each block, subset of components undergoes all possible combinations, while the remaining factors are held constant at their center levels. This design has multiple benefits, including the ability to code three levels as -1 (low), 0 (middle), and +1 (high), the creation of an independent quadratic design, and a simplified approach to organizing and interpreting the results. The design includes an incomplete block design, with each block comprising the highest and lowest values, factorial design values, and the core values of the factors A polynomial equation can be used for prediction of optimized result (Equation 2).

$$Y = \beta_0 + \sum \beta_i X_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j \quad (2)$$

Y is the predicted optimized value, β values are regression coefficients and Xi and Xj are independent variables (from 1 to 999) [14].

In this study, the statistical experimental design method has been used for the first time in the literature for MCFA production with *Clostridium kluyveri.* Box Behnken Design was used to achieve both product maximization and cost minimization in the costly chain elongation reaction by *Clostridium kluyveri*. Three independent variables were selected as pH, acetate and ethanol concentrations. The relevant statistical experimental design method was conducted at two different temperatures (30°C and 37°C), to observe the effect of temperature.

MATERIALS and METHODS

Growth Conditions and Activation of *Clostridium kluyveri* DSM 555

Clostridium kluyveri (DSM 555) bacteria purchased from DSMZ culture collection and medium 52. The components of the medium is as follows: (for 1000 mL); K-acetate, 10 g, K_2HPO_4,0.31 g, KH_2PO_4, 0.23 g, NH_4Cl, 0.25 g, $MgSO_4$ $7H_2O$, 0.20 g, Trace element solution, 1 mL, Selenite-Tungtate solution, 1 mL, yeast extract, 1 g, Sodium resazurin (%0.1), 0.5 mL, Ethanol-absolute, 20 mL, Na_2CO_3, 1 g, seven vitamins solution, 1 mL, L-cysteine, 0.25 g, Na_2S $9H_2O$, 0.25 g. Trace element solution in 1000 mL HCl (%25) 10 mL, $FeCl_2$ $4H_2O$, 1.5 g, $ZnCl_2$ 70 mg, $MnCl_2$ $4H_2O$, 100 mg, H_3BO_3, 6 mg, $CoCl_2$ $6H_2O$, 190 mg, $CuCl_2$ $2H_2O$, 2 mg, $NiCl_2$ $6H_2O$, 24 mg, Na_2MoO_4 $2H_2O$, 36 mg . Selenite Tungtate solution in 1000 mL; NaOH, 0.5 g, Na_2SeO3 $5H_2O$, 3 mg, Na_2WO_4 $2H_2O$, 4 mg. Seven vitamins in 1000 mL; Vitamin B12, 100 mg, p-aminobenzoic acid, 80 mg, D(+) Biotin, 20 mg, Nicotinic acid, 200 mg, Ca-pantothenate, 300 mg, Thiamine HCl_2H_2O, 200 mg, Pyrodoxine hydrochloric acid, 300 mg. To validate viability of the bacteria, a gram staining procedure was applied [15]. The medium was sterilized at autoclave (HİRAYAMA) and inoculated by 10% in 50 mL serum bottles. After inoculation the head space was flushed with 20% CO_2, 80% N_2. The serum bottles were kept at 37°C. The bacteria were transferred into fresh medium every 2 weeks for keeping active. Since the growth of bacteria is maximized on 48 th hour, the experiments were conducted after 48 h growth of bacteria.

Box Behnken Experimental Design Methodology

Box Behnken methodology was applied for optimization of concentrations of K-acetate and ethanol for chain elongation reaction. The experimental conditions for each batch reactors are as in Table1. The same set of experiments was also repeated at 30°C and 37°C to evaluate the effect of temperature.

Table 1. The experimental conditions for Box-Behnken design*

	K-acetate Concentration (g/L)	Ethanol Concentration (g/L)	pH
Low (-1)	2	8	5
Medium (0)	6	24	6.5
High (+1)	10	40	8

*: The results were analyzed using Design Expert 7.0 trial version.

Batch Reactors

50 mL serum vials were used as batch reactors. All reactors were capped with rubber stopper and sealed with aluminum ring. The reactors were inoculated by 10% using 48 h growth *Clostiridum kluyveri*. The headspace of the reactors was flushed with 20% CO_2 and 80% N_2 gas mixture. Each design has 15 reactors with different medium compositions. All experiments were performed in duplicates for 30°C and 37°C. The reactors were kept at temperature-controlled incubator (Thermoscience).

Analytical Methods

Samples were collected from the reactors daily by removing 2 mL of reaction medium. Firstly, the OD at 600 nm values were measured using UV spectrophotometer (Thermoscience). The pH values were determined using pH strips (Merck). The samples were centrifuged for 10 mins at 5000 rpm to remove the biomass. After centrifugation the supernatant was filtered through syringe filter with 0.20 µm pore size PTFE filter. The filtered samples were collected in 1.5 mL vials for chromatographic analysis. The MCFAs (acetic acid, butyric acid, hexanoic acid and ethanol) in the medium were analyzed by a High-Pressure Liquid Chromatography (HPLC) (Thermo Fisher Scientific, USA). A solution of 5 mM H_2SO_4 was used as the mobile phase in the HPLC system. After a 5-minute purge to remove air bubbles, the column was heated, and the RID was purged for 30 minutes at 0.8 ml/min and set to 55°C. Filtered samples were diluted 1:10 with ultrapure water and placed in vials for analysis. Calibration standards (100, 500, 25, 12.5, 6.25 mM) were run in triplicate for calibration [16].

RESULTS and DISCUSSIONS

Following the activation of *Clostridium kluyveri*, studies were conducted using statistical experimental design in batch reactors at temperatures of 30°C and 37°C. The measurement findings obtained from the experimental settings were evaluated using a statistical software.

Following the analysis, the results were analyzed, and cost comparisons were also carried out.

MCFA Production Optimization at 30°C

The optimal growing temperature for *Clostridium kluyveri* has been reported to be 37°C. Besides in this study, 30°C, which is the optimum temperature for activity of *Clostridium* species, was also applied investigate the production of MCFA at lower temperatures. Subsequent tests were conducted accordingly.

In order to investigate the growth of bacteria in the samples collected from reactors over 15 different medium compositions, optical density (OD) measurements were conducted using a UV spectrophotometer at 600 nm wavelength. A significant rise in optical density (OD) values was recorded during trials 3 and 10 where values remained constant after the second day. In reactors 1, 8, 9, 14 there was a quick lag phase followed by an exponential growth phase that lasted until day 4, after then the stationary phase was observed. No growth was found in tests 5, 8, 10, 11, and 15. Based on the bacterial growth performances, it is evident that certain media compositions and temperature values of 30°C are unsuitable for the rapid development of *Clostridium kluyveri.* Because the maximum growth values are 0.35-0.40 The positive effect of medium composition was observed in several tests (Figure 1).

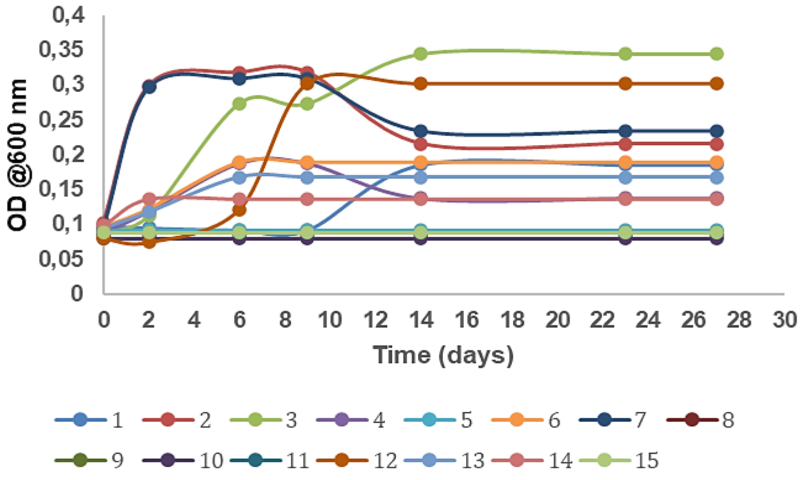

Figure 1. Growth performances of *Clostridium kluyveri* at 30°C

According to the results of pH analysis conducted on the final day of the experiments, it was noticed that the pH remained constant in the reactors without growth, whereas the pH reduced in the reactors with growth because of organic acid production (Table 2). The main goal was to optimize hexanoic acid production from the volatile fatty acid values produced in the reactors, as it is the key component used as an additive in MCFA production. Table 2 also shows the hexanoic acid production results used in statistical optimization analysis. As it can be seen from the results hexanoic acid production is directly related with bacterial growth. These results were analyzed in Design Expert software and the ANOVA results are on Table 3.

Table 2. Experimental results for hexanoic acid production and final pH values.

Exp. No	Acetate Concentration (g/L)	Ethanol Concentration (g/L)	Hexanoic Acid Concentration (g/L)	Initial pH	Final pH
1	6	40	6.72	5.0	5.0
2	6	8	3.12	5.0	4.5
3	2	24	3.17	5.0	4.5
4	10	8	4.05	6.5	5.0
5	2	24	0.07	8.0	6.0
6	2	40	1.99	6.5	5.0
7	10	24	3.66	5.0	4.5
8	6	8	0.09	8.0	6.0
9	6	40	7.48	8.0	6.0
10	10	40	0.06	6.5	6.5
11	2	8	0.31	6.5	5.0
12	10	24	8.33	8.0	5.0
13	6	24	3.80	6.5	6.5
14	6	24	7.50	6.5	5.0
15	6	24	0.05	6.5	6.5

Table 3. ANOVA (partial sum of squares-Type III) results of Box Behnken Design for 30°C

ANOVA for Response Surface Quadratic Model						
Source	Sum of square	df	Mean square	F value	p value Prob>F	
Model	112.76	9	12.529	5.020	0.045	significant
A-Acetate conc.	0.11	1	0.106	0.042	0.845	
B-Ethanol conc.	0.49	1	0.490	0.196	0.676	
C-pH	33.46	1	33.456	13.406	0.015	
AB	0.93	1	0.931	0.373	0.568	
AC	0.06	1	0.055	0.022	0.888	-
BC	3.29	1	3.294	1.320	0.303	
A^2	33.04	1	33.037.-	13.238	0.015	
B^2	18.55	1	18.547	7.432	0.042	
C^2	33.93	1	33.927	13.595	0.014	
Residual	12.48	5	2.496	-	-	
Lack of fit	12.01	3	4.002	17.0100	0.056	not significant
Pure error	0.47	2	0.235	-	-	-
Core total	125.24	14	-	-	-	

Figure 2 shows that predicted and experimental values of the model are quite close to each other. Since the R^2 value was close to 1, shows that results have strong regression. The close alignment between the predicted and actual values indicates the significance of the model. The fact that the predicted and actual values are very close to each other shows that the results of the experiments are significant.

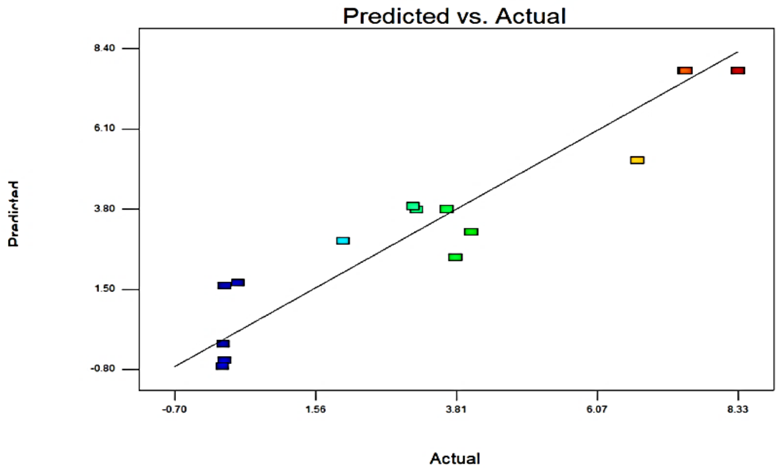

Figure 2. The relationship between the actual and the predicted values at 30°C

Figure 3 shows the results of Box-Behnken Design. The 3D plot and contour plot derived from the Box-Behnken Design (BBD) experiments visually represents the relationship between acetate concentration (A) and ethanol concentration (B) in the process of optimizing hexanoic acid production. The color gradient ranging from green to red signifies different production levels, with the central red area denoting the maximum yield. The middle region indicates the ideal circumstances for achieving the highest possible production of hexanoic acid, indicating that certain levels of acetate and ethanol are very efficient. The progressive increase in production towards the optimal point is indicated by the smooth, concentric contour lines, which illustrate the considerable interaction effects between the two variables. The experimental data points, depicted as red dots, are evenly dispersed throughout the design space, ensuring the reliability of the response surface model. According to Figure 3 and also as reported in Table 3, the statistical optimization experiments were successful in terms of a fit to model, and a significant surface response model was acquired. Figure 3 depicts the conditions with the highest hexanoic acid concentration are for acetate (4-8 g/L) and for ethanol (16-32 g/L). The BBD technique showcases efficacy by minimizing the number of experimental trials needed, while also offering a thorough comprehension of the system's behavior. The results emphasize the significance of focusing on the specific ideal area to attain the highest output of hexanoic acid, thereby validating the effectiveness of the BBD methodology in optimizing biochemical production processes. According to Figure 3, a surface response model was statistically significant and optimization experiments were successful. According to this graph, the conditions with the highest hexanoic acid concentration are for acetate (4-8 g/L) and for ethanol (16-32 g/L). The optimum condition for hexanoic acid production is suggested as; 5.94 g/L acetate, 24.23 g/L ethanol and pH=5.99 with a desirability value of 0.974. Accordingly, optimum pH value is 6 and the Acetate/Ethanol concentration ratio is 1/4 for maximizing hexanoic production. A similar observation Acetate/Ethanol concentration ratio was also in line with literature [17]. On the other hand, this ratio can vary between different strains of bacteria. According to the optimization results, a maximum yield of 4 g/L of hexanoic acid can be produced at 30°C.

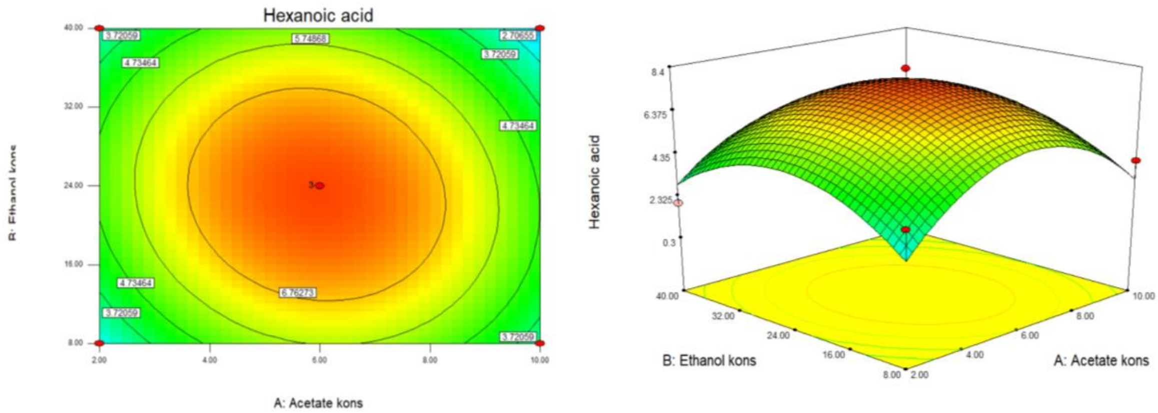

Figure 3. Effect of acetate and ethanol concentrations on hexanoic acid production values (30°C, pH:5.5)

MCFA Production Optimization at 37°C

Figure 4 shows the optical density (OD) at a wavelength of 600 nm as a function of time (in days) for various reactors with different medium compositions at a temperature of 37°C. In most of the runs, there was a fast increase in OD, indicating exponential growth. The growth data for reactors 3 and 10 indicate a significant increase within the initial 10 days. Once the reactors reached a maximum optical density (OD) mostly at the end of 10-15 days, their growth stabilized for each run. Certain reactors consistently exhibit a low optical density (OD) for the whole duration, revealing that there was a slow or no bacteria growth. For example, reactors 6, 9 and 15 showed no growth. Reactors 3, 4 and 13 exhibited the highest optical density (OD) values, reaching approximately 0.6, whilst reactor 1 and others had OD values below 0.2. Some reactors showed a long lag phase characterized by a minimal or nonexistent increase in optical density (OD) at the first stage. For example, reactor 13 showed a gradual increase beginning on day 8.

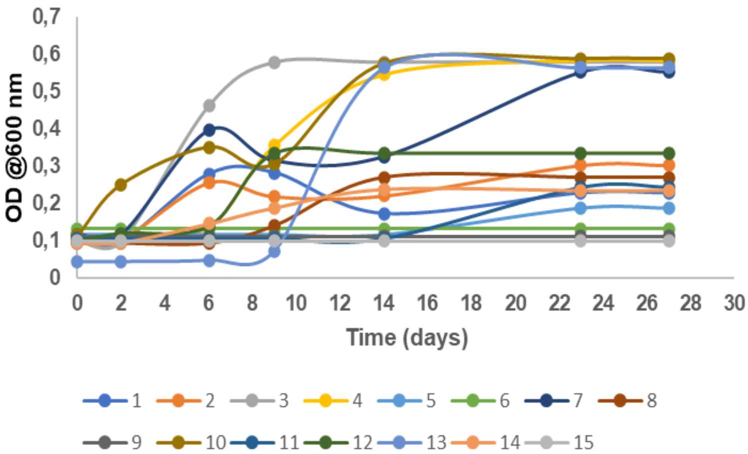

Figure 4. Growth performances of *Clostridium kluyveri* at 37°C

The two figures represent a comparative evaluation of OD measurements at 600 nm over a period of 30 days (Figure 1 and 4). In the initial plot, the OD values remained constant around day 14, with the maximum recorded OD being approximately 0.35 and an estimated mean OD of 0.2. The highest growth values were obtained between days 6 and 14.
On the other hand, the second plot exhibited notably elevated OD values, characterized by peaks at roughly 0.6 and an average OD of around 0.3, suggesting more advantageous growing circumstances. The higher average optical density (OD) indicated higher microbial growth, indicating that the second set of experimental settings or strains was more successful in increasing cell density. Figure 4 highlights the significance of choosing ideal conditions for higher optical density (OD) values, indicating improvement of product yields and overall efficiency of the process. Therefore 37°C is more productive for growth of *Clostridium kluyveri,* as also suggested in literature [17].

The results obtained in the experiments performed at 37°C were also significant with a high significance value ($p=0.0001<0.05$). The experimental results are significant, and the model is strong. Accordingly, the optimization results are also significant values (Table 4).

Table 4. ANOVA (partial sum of squares-Type III) results of Box Behnken Design for 37°C

ANOVA for Response Surface Quadratic Model						
Source	Sum of square	df	Mean square	F value	p value Prob>F	
Model	132.12	9	14.679	60,486	0.0001	significant
A-Acetate conc.	0.17	1	0.168	0,693	0.4431	
B-Ethanol conc.	14.91	1	14.906	61,418	0.0005	
C-pH	27.98	1	27.975	115,270	0.0001	
AB	0.86	1	0.865	3,564	0.1177	
AC	23.81	1	23.814	98,125	0.0002	
BC	2.02	1	2.016	8,308	0.0345	-
A^2	22.79	1	22.786	93,886	0.0002	
B^2	32.77	1	32.771	135,030	< 0.0001	
C^2	16.04	1	16.038	66,085	0.0005	
Residual	1.21	5	0.243	-	-	
Lack of fit	1.12	3	0.372	7,737	0.1166	not significant
Pure error	0.1	2	0.048	60,486	0.0001	-
Core total	133.33	14	-	0,693	0.4431	

Figure 5 exhibits the correlation between the values obtained from the experimental set and the values predicted by the model. It was observed that the values were quite close to each other.

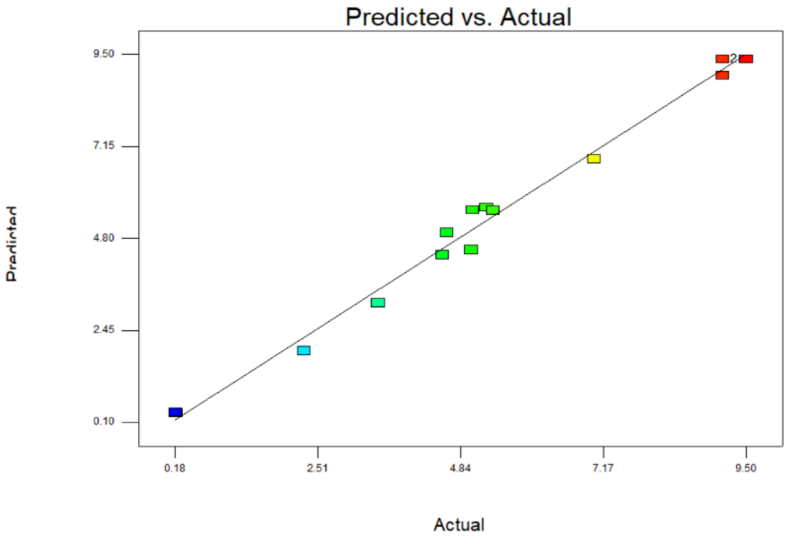

Figure 5. Relationship between values obtained in MCFA production and predicted values (37°C)

R^2 value was calculated as 0.9909. Figure 6 shows the three-dimensional graphics of the model. According to the graph, the ranges where the acetate concentration is 6-8 g/L and ethanol concentration 14-20 g/L.

The highest concentration of hexanoic acid, roughly 9.7 g/L, was achieved when the acetate concentration was around 8.0 g/L and the ethanol concentration is at 24.0 g/L. For optimization, the two independent variables are adjusted in a way that achieves the maximum yield of hexanoic acid. At the lowest and highest levels of acetate and ethanol concentrations, the concentration of hexanoic acid decreased. On the other hand, the hexanoic acid concentration reached its lowest point at approximately 3.65 g/L when the acetate concentration was 2 g/L and the ethanol concentration was 8 g/L. This indicated that both excessively low and excessively high concentrations of the substrates had a detrimental effect on the synthesis of hexanoic acid. The minimum and maximum acetate concentrations were 2.0 g/L to 10.0 g/L; ethanol concentrations were from 8.0 g/L to 32.0 g/L. The hexanoic acid production values are found to be between 3.65 g/L to 9.7 g/L.

The optimization was performed using the equation derived from the experimental results in the model. In numerical optimization, maximization of hexanoic acid production while keeping other variable ranges at intermediate values. The production of 9 g/L hexanoic acid was achieved at 37°C with concentrations of 6.12 g acetate /L and 24.45 g ethanol /L, and a pH value of 5.43.

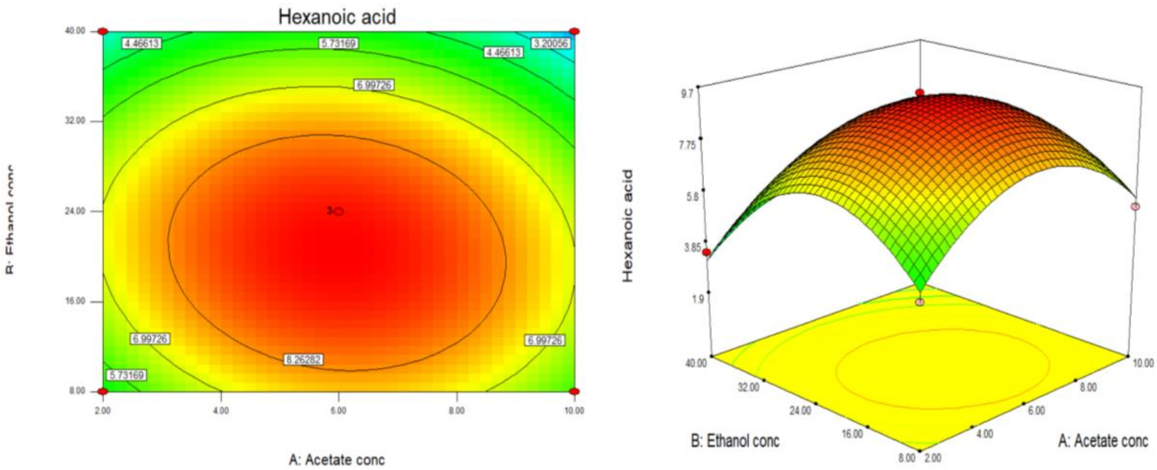

Figure 6. Effect of acetate and ethanol concentrations on hexanoic acid production values (37°C, pH 5.5)

Hexanoic acid production from ethanol and acetate using Clostridium kluyveri was also investigated in previous studies in literature. In another study, the highest hexanoic acid concentration of 8.42 g/L was achieved with an ethanol/acetate ratio of 10:1 (550 mM total carbon). The production rate increased with higher ethanol concentrations, but concentrations above 700 mM inhibited the biosynthesis process. Optimal conditions for caproate production including a defined acetate/ethanol ratio and controlled substrate concentrations proved to be significant on yields and efficiencies [17]. In current study, acetate/ethanol ratio was reduced by 2.5 times while higher concentrations resulted in inhibition of microorganism activity. Therefore, continuous bioreactors can be used to maintain microbial activity without loss of performance.

In a study by Ge et al. [18], spent yeast fermentation beer waste was processed using an anaerobic sequential batch reactor at pH 5.5. An average hexanoic acid production rate of 3.38 g/L/d (based on COD) was achieved with a yield of 70.3 % and an hexanoic acid/ethanol ratio of 1.19 after 55 days. The peak production rate was reached by increasing the organic loading rates, boosting the capacity of the extraction system, and altering the complex feedstock batch [18]. In another study by Grootscholten et al [19], using acetic acid and ethanol in a continuous reactor with a low hydraulic retention time (HRT) of 17 h in an anaerobic filter at pH 7.0 resulted in a high production rate of 15.7 g/L/d and a yield of 11.1 g/L of hexanoic acid.

The same group also reported that lowering the HRT to 4 hours under identical operational conditions resulted in a threefold improvement in the production rates of MCFA [20]. Moreover, the MCFA production can be improved by using two stage reactors. Different types of organic source can be used for MCFA production. For instance, 12.6 g/L/d of MCFA production was achieved by using municipal solid waste [21, 22]. First step can be the application of chemical inhibition for anaerobic bacteria to prevent the competition between anaerobic mixed culture and chain elongating culture. A real time study with syngas fermentation effluent by integrating the carboxylate platform to the syngas platform using initially Clostridium ljungdahlii strain ERI-2 for the production of precursors of the chain elongation reactor in the first reactor and then using the second reactor to produce MCFA with *Clostridium kluyveri*. The highest concentration 1g/L of hexanoic acid was produced at a pH 5.44 with a production rate of 1.7 g/L/d [23]. It can be generally observed that batch reactors generally show moderate production rates and yields. Therefore, continuous production of hexanoic acid with optimized medium conditions is suggested to improve the yields and reduce the costs. San Valero et al. 2022 [24] also focused on the effects of pH, yeast extract and addition of $NaHCO_3$ with continuous bioreactor and achieved 21.4 g/L hexanoic acid production at a pH value between 5.5-6.5, which is similar value observed in current study.

Cost Analysis

The Table provides the cost analysis comparative values while utilizing optimal recipes at a temperature of 37°C. The data in this table was obtained from the official website of Merck. The price of one liter of the media components suggested by DSMZ was determined to be 9.92 €, but the price of the optimized media components was determined to be 8.47 €. Upon comparing the media expenses, it becomes evident that a savings of around 15% in costs has been accomplished. Although this value may seem negligible for laboratory scale experiments, it becomes considerably more significant when applied to larger-scale and commercial applications.

Table 5. Results of cost analysis

	DSMZ medium	Optimized medium
Macro chemicals (including K-acetate)	€ 6.67000	€ 4.59470
Trace elements	€ 0.00147	€ 0.00147
Sodium selenate	€ 0.00009	€ 0.00009
7 vitamins	€ 0.08611	€ 0.08611
Ethanol	€ 3.16000	€ 3.79200
Total cost	€ 9.91767	€ 8.47437
Cost advantage	-	14.55%

CONCLUSION

In this study, optimization of hexanoic acid production from acetate and ethanol via chain elongation reaction was performed by using a statistical experimental design method. In the production of hexanoic acid by chain elongation reactions, a temperature of 37°C is required for the growth and active production of *Clostridium kluyveri*. Statistical experimental design is a crucial technique that efficiently reduces both time and money in microbiological processes. The ideal ratio of acetate to ethanol concentration for the synthesis of hexanoic acid with *Clostridium kluyveri* in batch reactors was determined to be 1:4 by statistical experimental design. An enhanced ambient medium composition resulted in a 14% decrease in process costs.

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Research Paper / Araştırma Makalesi

Assessment of Agricultural Virtual Water Export of Türkiye

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ABSTRACT

As the negative effects of climate change are amplified, the agriculture sector is becoming more fragile. Food security is under risk because agriculture is highly dependent on climatic conditions and availability of water resources all over the world. For this reason, the concepts of virtual water and water footprint have begun to gain importance as decision-support tools for the effective and efficient use of water. However, there is a gap in the literature, where few studies focus on virtual water trade. Given the increasing stress caused by reasons such as the scarcity of water resources and climate change, this concept is likely to gain serious attention in the coming years. Türkiye is a water-stressed country whose water resources are decreasing due to the impact of climate change. More effective water management is needed to meet the increasing demand. In this study, virtual water was determined for Türkiye's agricultural export, and it was observed that crops with high water footprint but low economic returns were also exported in large amounts. It was revealed that the virtual amount of water exported by the evaluated crops was 5.9 billion m^3 annually. This value is high enough to meet the domestic water needs of a metropolitan city like Istanbul for seven years. It is evident that water footprint and virtual water concepts would help decision makers to support optimized water consumption and sustainable water management.

Keywords: Exported crops, Virtual water trade, Water footprint

Türkiye'nin Tarımsal Sanal Su İhracatının Değerlendirilmesi

ÖZ

İklim değişikliğinin olumsuz etkileri arttıkça tarım sektörü daha da kırılgan hale gelmektedir. Tarımın tüm dünyada büyük ölçüde iklim koşullarına ve su kaynaklarına bağımlı olması nedeniyle gıda güvencesi tehlikeye girmektedir. Bu nedenle suyun etkin ve verimli kullanılmasında karar destek araçları olarak sanal su ve su ayak izi kavramları önem kazanmaya başlamıştır. Ancak literatürde bu konuyla ilgili çalışmalar halen yetersizdir; çok az çalışma sanal su ticaretine odaklanmaktadır. Ancak su kaynaklarının kıtlığı ve iklim değişikliği gibi nedenlerin yarattığı stresin giderek arttığı göz önüne alındığında, bu kavramın önümüzdeki yıllarda ciddi anlamda ilgi görmesi muhtemeldir. Türkiye açısından bakıldığında da literatürde çok az sayıda çalışma bulunmaktadır. Türkiye, su stresi yaşayan ve iklim değişikliğinin etkisiyle su kaynakları azalan bir ülkedir. Artan talebi karşılamak için daha etkili bir su yönetimine ihtiyaç vardır. Bu çalışmada Türkiye'nin tarımsal ihracatının sanal su içeriği değerlendirilmiş ve su ayak izi yüksek ancak ekonomik getirisi düşük olan ürünlerin de büyük miktarlarda ihraç edildiği görülmüştür. Değerlendirilen ürünlerle birlikte ihraç edilen sanal su miktarının yıllık 5.9 milyar m^3 olduğu bulunmuştur. Bu değer İstanbul gibi bir metropolün yedi yıllık evsel su ihtiyacını karşılayabilecek düzeydedir. Bu durum, su ayak izi ve sanal su kavramlarının ticari uygulamalarda dikkate alınması durumunda ülkenin su kaynaklarının verimliliği açısından çarpıcı sonuçlar elde edeceğini göstermektedir.

Anahtar Kelimeler: İhraç edilen tarım ürünleri, Sanal su ticareti, Su ayak izi

INTRODUCTION

Food is in greater demand as the global population continues to grow. However, the amount of food production cannot keep up with the increasing demand. Food security is becoming a global concern in recent years. More than 333 million people are already facing acute levels of food insecurity [1]. One of the biggest factors leading to global food insecurity is climate change as agriculture is highly dependent on climate. Global warming is influencing weather patterns, causing heat waves, heavy precipitation, and droughts [2]. A global warming of 1.5-2°C during the 21st century is expected unless serious reductions occur in CO_2 and other greenhouse gas emissions [3]. Millions of people are negatively affected due to increased natural disasters as a result of climate change. Floods are occurring more frequently and more severely due to changing rainfall patterns and melting glaciers. Sea levels are rising rapidly as a result of further melting of the Arctic and Antarctic ice sheets [4].

Environmental analyses carried out in various industrial areas have shown that although waste materials have different characteristics in terms of volume and composition, they are usually discharged with little or no treatment [5]. The sustainability of water resources depends on the fact that water resources are not polluted. Agriculture contributes to climate change due to environmental and water pollution and is affected by climate change as one of the most vulnerable and water-dependent sectors. Both as a result of the negative effects of climate change and due to water pollution, limited water resources are becoming increasingly scarce, which leads to a direct impact on agricultural production. The fact that 69% of the water on Earth is withdrawn for agricultural use is evidence of the dependency of the sector on water [6].

Located in the Mediterranean Basin, Türkiye is one of the countries expected to be most affected by climate change. A significant warming on Türkiye is expected during the 2015-2100 period according to the ClimaHydro Project performed by the Ministry of Agriculture and Forestry [7]. The project also predicted that the temperature increases will reach 3.4°C according to the RCP4.5 scenario and 5.9°C according to the RCP8.5 scenario for the 2090-2100 projection period.

Along with the effects of climate change on temperature in Türkiye, its effects on water resources are also inevitable. Türkiye is one of the countries with limited water resources. Turkey's annual water potential is 112 billion m^3 and the average precipitation is 574 mm/year. Additionally, the annual per capita water availability was reported as 1346 m^3 in 2020 [8]. According to the Falkenmark indicator [9], Türkiye is considered a water-stressed country. When the impacts of climate change on the water resources of Türkiye are investigated on a basin level, projections show that the Euphrates-Tigris Basin will have the most significant water deficit according to all scenarios and projection periods. Additionally, a substantial water deficit is expected for the Eastern Mediterranean and Konya Closed Basins [7].

As the importance of food security continues to grow, the concepts of water footprint and virtual water trade have emerged as important tools for assessing and measuring water use in food production and trade, particularly in the context of climate change and adaptation strategies. There is a strong decoupling between the food trade and virtual water. When countries trade food, they also exchange virtual water along with goods. However, the concept of virtual water trade is not considered yet in international trade practices. Virtual water trading can be a valuable tool for water-scarce countries to optimize their water use. In a world where water resources are decreasing, this aspect of trade may emerge as a very important research area in the future.

Water footprint was first introduced by Arjen Hoekstra in 2002 [10]. Water footprint is a measure of water utilized in relation to consumer goods [11]. It quantifies the freshwater volume required to produce a particular product by considering the different stages of the production process. There are three components of water footprint as Water Footprint Network [12] defines; green water footprint, blue water footprint and grey water footprint. Green water footprint (WFgreen) refers to the precipitation water stored in the root zone of the soil and evaporated, transcribed by plants, or absorbed by them. It is crucial for agriculture, forestry, and horticulture products. Blue water footprint (WFblue) is the water which has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Irrigated agriculture, industry and domestic water use can have a blue water footprint. On the other hand, grey water footprint (WFgrey) is related to pollution; it is the amount of freshwater required to dilute the pollution to acceptable levels required by the legislation.

Virtual water was introduced by Tony Allan at the beginning of 1990. It is the water embodied in a product in a virtual sense. It refers to the water needed to produce the product, and it has also been called "embedded water" [13]. Each product contains virtual water in different proportions depending on the processing methods of the products and the conditions of the production areas. If a country exports goods to another country the water used in its production is also exported which refers to virtual water trade. There is a strong relationship between the trade of virtual water and food. It becomes beneficial, especially for water-scarce countries when they import water-intensive products instead of producing them with their limited water resources. Virtual water trade plays a vital role for water-scarce countries to optimize their water usage.

There are very few studies evaluating the virtual water trade of Türkiye. The study of Hoekstra and Hung [14] stated that Türkiye is a virtual water importer country.

The study conducted by World Wide Fund for Nature (WWF) [15] indicated that the water budget is balanced in exports and imports. However, in these studies, only a general comprehensive evaluation was made for Türkiye's virtual water exports. There are only a few studies conducted to calculate the water footprint of certain products or areas in Türkiye. The study conducted by WWF Türkiye [15] is the most comprehensive and timely study conducted in the field.

Studies focusing on virtual water trade are quite new in the literature and there is a knowledge gap on this subject. Considering the increasing stress caused by scarcity of water resources and climate change, this concept is likely to gain serious attention in the coming years. Türkiye is a country suffering from water shortage, with its water resources decreasing due to the impact of climate change. More effective water management is needed to meet increasing demand. In this regard, this study has promising results to raise awareness and lead to new studies on virtual water trade concept in Türkiye and beyond.

To this end, the aim of this study is to determine the virtual water content of Türkiye's most exported crops by identifying the key exported crops in terms of quantity, economic value and water footprint. It is also aimed to suggest solutions for reducing the exported virtual water of Türkiye by identifying crops with high water footprints, especially blue water which shows the dependency on irrigation.

METHODOLOGY

A literature review was made to determine the impacts of climate change on Türkiye’s agricultural production. Next, the most exported crops were determined to examine Türkiye's virtual water trade. Detailed information on the provided data and assessment of the virtual water export of Türkiye is given below.

The data of the exported crops in terms of quantities and economic values were obtained from UN Comtrade to determine Türkiye's agricultural virtual water exports [16]. The data for the 2013-2020 period was used. Then, the obtained data were averaged over the years 2013-2020 on Excel and put in two ranks in terms of quantity (ton) and economic value ($). The top ten products according to the ranking were included in the study.

The global green and blue water footprints (m^3/ton) of these crops presented in Water Footprint Statistics (WaterStat) which provides data on blue, green and gray footprints broken down by product type and country were evaluated to determine how much water is used on average to grow those crops [17]. Global average water footprint data was provided from the study conducted by Mekonnen and Hoekstra [18]. Next, as seen in Equation 1, the data was multiplied by the amounts (ton/year) exported by Türkiye to reveal how much water was averagely exported in total. According to the result, a ranking was made from the highest water footprint to the lowest and the result was evaluated.

$$\text{Virtual Water Export (m}^3\text{/year)} = \text{Export Amount (ton/year)} \times \text{Water Footprint (m}^3\text{/ton) [19]} \qquad \text{(Equation 1)}$$

RESULTS and DISCUSSION

Türkiye’s average agricultural export is 32,907,488 tons/year, and the income from this export is 32.3 billion USD/year (2013-2020). Table 1 and Table 2 show the top 10 crops exported by net weight and value for the 2013-2020 average. It can be seen from the tables that the most exported crops in terms of value bring almost twice as much income as the most exported crops in quantity. Hazelnuts, tobacco, apricots, figs, and cotton are not among the most exported products in terms of quantity. However, these crops are important in terms of their economic value [20].

The study calculating Türkiye's water footprint carried out by WWF revealed that while the share of agricultural products (including both processed and unprocessed) in the total water footprint of exports was 53%, the total economic export value was only 10% [15]. Considering that Türkiye is not a water-rich country, it is obvious that it is not a good practice to export products that do not add value to the country but have a high share in water consumption.

In Figure 1, the global water footprints of the crops determined in terms of quantity and value are given. It is seen that crops such as lentils, hazelnuts and cottons have high global water footprints when considering the total water footprint. On the contrary, crops such as grapes, oranges and tomatoes have the lowest water footprint. On the other hand, hazelnuts, cotton, and figs have the highest blue water footprint which means they require more irrigation water to produce those crops.

Table 1. Top 10 crops exported (net weight) (average between 2013 and 2020) [16]

Crops	Net Weight (tons/year)	Trade Value (USD/year)
Mandarins	1.227.508	620.124.313
Tomatoes	525.608	327.269.452
Maize	477.391	119.632.681
Lemons	473.263	290.426.975
Grapes	459.567	650.971.088
Oranges	340.133	158.024.727
Bananas	323.224	167.130.616
Lentils	315.554	270.853.933
Rice	246.186	137.044.055
Apples	179.262	67.450.169
Total	4.567.696	2.808.928.009

Table 2. Top 10 crops exported (value) (average between 2013 and 2020) [16]

Crops	Trade Value (USD/year)	Net Weight (ton/year)
Hazelnuts*	1.194.617.963	158.064
Grapes	650.971.088	459.567
Mandarin	620.124.313	1.227.508
Tobacco*	367.933.749	50.181
Tomatoes	327.269.452	525.608
Apricots*	323.159.795	140.823
Lemons	290.426.975	473.263
Figs*	274.080.185	76.923
Lentils	270.853.933	315.554
Cotton*	194.330.278	106.522
Total	4.513.767.731	3.534.013

*Crops different from the list in terms of net weight

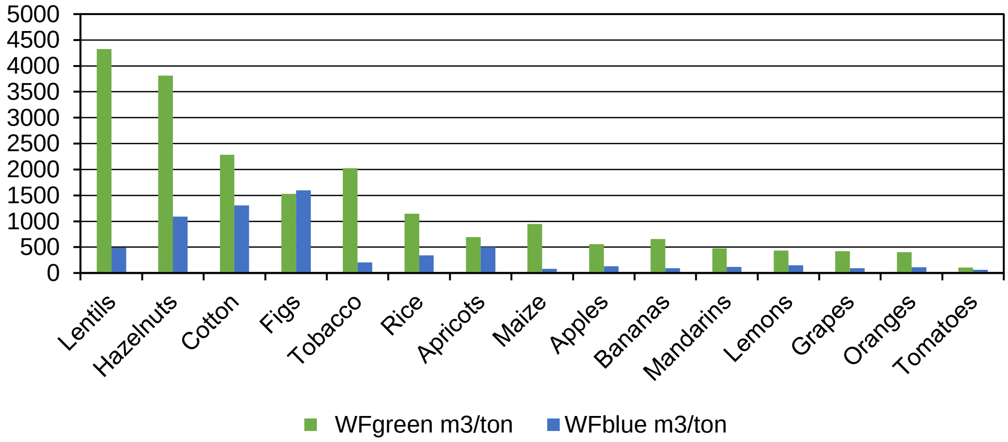

Figure 1. The global water footprint of the crops by m^3/ton [18]

In Figure 2, the water footprint of the determined crops is given according to the calculation of the global water footprint and export amounts of crops. The results show that the export of lentils, hazelnuts and mandarins has the highest total water footprint. Although the global water footprint of hazelnuts is seven times higher than that of mandarins, when the export amounts are considered, virtual water exported is similar for both crops. Additionally, the water footprint of maize is quite high, and it is exported in large quantities despite its little contribution to the economy. On the other hand, crops such as apricots, tobacco and tomatoes have a low water footprint, and they are also the crops that have a major contribution to the country’s economy. Finally, despite the relatively low total water footprint of fig export, it is seen from the table that the share of blue water footprint is higher than the green water footprint, which means it is dependent on irrigation (surface or ground-water).

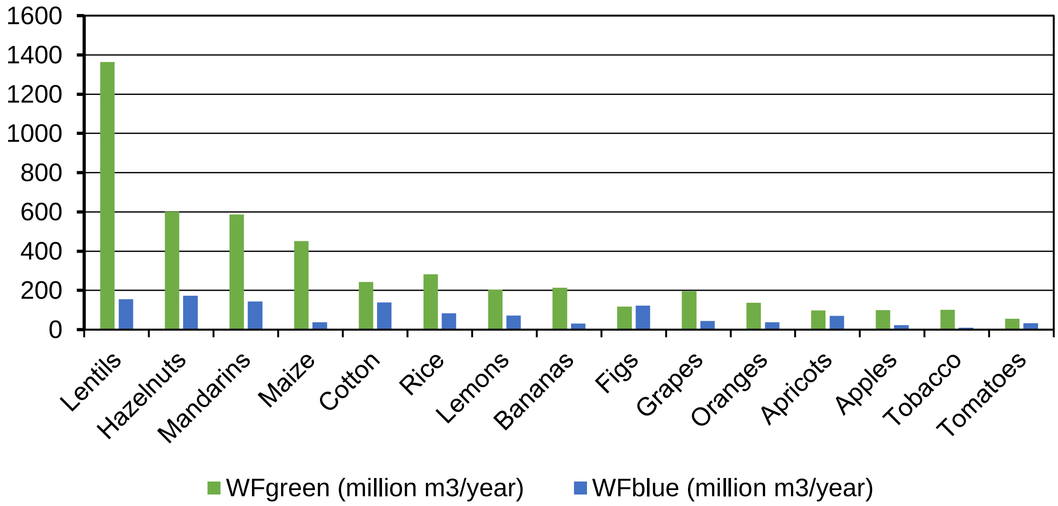

Figure 2. The virtual water export of the crops (million m^3/year)

In Figure 3, it is seen that the blue virtual water export associated with lentil is quite high, yet lentils remain one of Türkiye's most exported crops. Despite the high water footprint and huge amounts of export, it is not included in the list of products that contribute to the economy. In contrast, although crops such as tobacco, bananas, oranges, apples, and tomatoes are exported in large quantities, the blue virtual water export is low. The amount of water used for agriculture in Türkiye which represents irrigation water is 44 billion m^3 [8]. The blue virtual water export of the evaluated crops is more than 1.1 billion m^3. This means that 1.1 billion m^3 of the total water used in agriculture is exported virtually only through the export of the crops evaluated in the study.

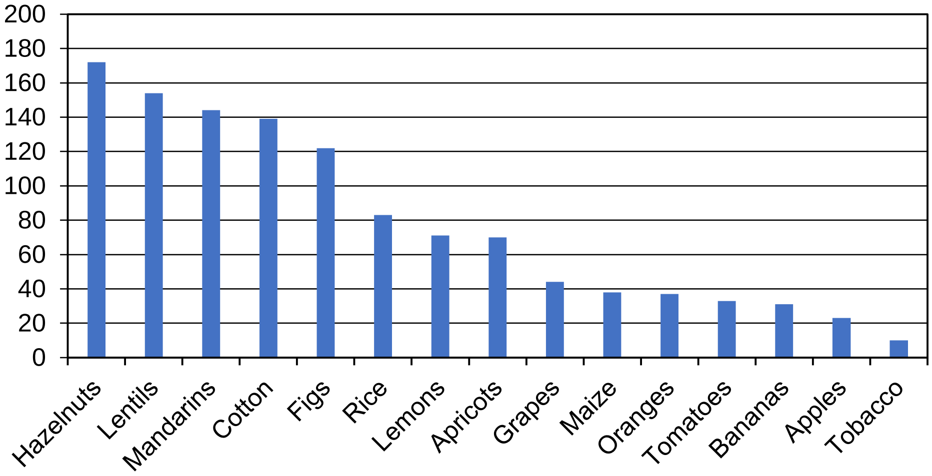

Figure 3. The blue virtual water export of crops (million m^3/year)

The grey water footprint of the most exported crops is found as 1 billion m^3 which is the amount of water used to dilute the water pollution caused by the production of these crops. However, it was not included in the virtual water trade calculation as it corresponds to the pollution created by crop production and while the green and blue water of the country is exported, pollution remains in the country.

As Figure 4 shows, the export of rice needs to be reduced due to its high water footprint, large export volumes and low economic value. Additionally, in terms of economic return, cotton exports need to be reduced due to their large water footprint. However, despite hazelnuts and figs having large blue water footprints like cotton, they have been determined as two of the most important crops in Türkiye's exports, within the scope of the CREATE (Cross-Border Climate Vulnerabilities and Remote Impacts of Food Systems of the EU, Türkiye and Africa: Trade, Climate Risk and Adaptation) project (The project was funded by H2020 ERANET FOSC program, carried out under the coordination of Ankara University Water Management Institute with partners from the Netherlands, Türkiye and Morocco, and led by Prof. Gökşen Çapar in the period of 2021-2024). On the other hand, exports of low water footprint, and high-income crops such as tobacco, grape and tomato should continue. At the same time, exports of crops such as bananas, oranges and apples need to be increased since they have a low water footprint even though they are exported in large quantities. In Figure 4, the data in the area outside the intersection of the blue water footprint with export and income is not available since it was out of the scope of the study.

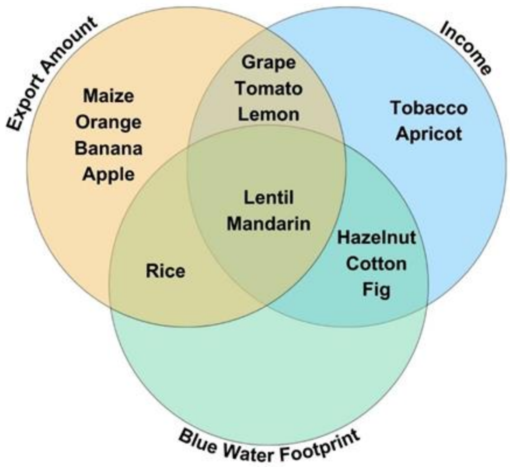

Figure 4. Crops with respect to export amount, income, and blue water footprint of export

Overall, when Türkiye's exported crops are examined in terms of both quantity and income, it is seen that some of the top-ranked crops are exported in high quantities despite their low income, while some crops have high income despite their small export quantities. One of the most important factors that stands out when examining these crops is the blue water footprint which represents irrigation water demand. Although some crops are exported in low quantities, virtual water exports are high when considered their blue water footprint. On the other hand, although the export amounts of some crops are high, virtual water exports are low because of the low blue water footprint.

CONCLUSION

The importance of water is inevitable in meeting the increasing food demand and ensuring food security. However, agriculture is very sensitive to climate change and the availability of water resources. To reduce the associated risks, it is necessary to focus on the efficient and sustainable use of water in areas where it is used intensively. For this reason, the importance of decision support tools such as water footprint and virtual water trade is becoming more significant to ensure sustainable management of water resources.

Türkiye is not a water-rich country. Therefore, the concept of virtual water can be a useful tool for more effective and efficient use of water. In this study, the crops highly exported by Türkiye were examined and it was determined how much water is exported with these crops on the average. The most exported crops were evaluated in terms of economic return, export amounts and global water footprint.

The product with the highest water footprint is lentils. Although it brings economic value, its large share in exports in terms of quantity also makes its share in virtual water exports high. Products such as tangerines, lemons, grapes, and tomatoes, which are among the most exported products in terms of quantity, have the lowest water footprints. While these products are exported the most in quantity, they are also among the products that contribute the most in terms of income. On the contrary, although the water footprints of crops such as hazelnuts, cotton, figs, and tobacco are high, their value in exports is low in quantity. Although they are exported in small quantities, they have high economic value.

This study examined whether Türkiye's most exported crops have high virtual water content and therefore whether the concept of virtual water should be recommended for inclusion in international trade practices. As a result of the calculations made in response to this, it was revealed that the virtual amount of water exported by the evaluated crops was 5.9 billion m^3 annually. This value is high enough to meet the domestic water needs of a metropolitan city like Istanbul for 7 years [21]. When the blue water component was compared with agricultural water use, the amount of virtual blue water exported was determined to be 1.1 billion m^3 per year. This corresponds to 2.5% of Türkiye's annual agricultural water use, which is reported to be 44 billion m^3. Based on the data obtained, the virtual water of exported crops is likely to become an important factor and a binding criterion in international trade practices. In this way, Türkiye will be able to make informed decisions on water allocation and sustainable practices that take water scarcity into account. This could help a water-stressed country like Türkiye to manage its limited water resources more efficiently and save significant amounts of water.

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Research Paper / Araştırma Makalesi

Using Household Fruit and Vegetable Waste in Recipes to Reduce Kitchen Food Waste and their Nutritional and Functional Values

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ABSTRACT

The formation of food waste brings numerous issues such as inefficient use of nutrients, social injustice, and economic and ecological losses. The aim of this study is to reduce fruit and vegetable waste, which are among the most common kitchen wastes, with new recipes, and to explore the advantages they provide to human health. The study developed 20 different recipes using parts typically considered waste in the kitchen, like stems, stalks, and peels from 11 fruits and 9 vegetables, and calculated their nutritional values using the BEBIS program (Nutrition Information System). Additionally, the functional properties of the fruit and vegetable waste used in the study were examined in light of scientific literature. Results showed that parts of fruits and vegetables considered as waste might have valuable nutritional properties, such as being a good source of dietary fiber, antioxidants, vitamins, and minerals. Among the recipes created with fruit waste, the chocolate balls with pomegranate peel powder had the highest energy value (4255.3 kcal), the sweet chicken with orange flavor had the highest protein content (122.1 g), and the watermelon dessert had the highest fiber content (25.3 g). Among the recipes made with vegetable waste, the puff pastry with leek leaves had the highest energy value (2740 kcal), and the savory cake with cauliflower and potatoes contained the most protein (222.2 g) and fiber (184.1 g). Using parts like stems, peels, and leaves considered food waste in recipes also imparts functional properties to the recipes. The food waste used in this study possesses properties in the literature such as anti-cancer, antimicrobial, antiviral, anti-inflammatory, prevention of neurological disorders, and anti-obesity, anti-diabetes, and anti-aging effects.

Keywords: Food waste, Vegetables, Fruit, Functional food, Gastronomy

Mutfakta Gıda Atıklarının Azaltılması Amacıyla Evsel Meyve-Sebze Atıklarının Tariflerde Kullanılması ve Oluşturulan Tariflerin Besinsel ve Fonksiyonel Değerleri

ÖZ

Gıda atık oluşumu; besinlerin etkin kullanılamaması, sosyal adaletsizlik, ekonomik ve ekolojik kayıplar gibi birçok sorunu beraberinde getirmektedir. Bu çalışmanın amacı, mutfaklarda en fazla oluşan atıklardan meyve ve sebze atıklarının yeni tariflerle azaltılması ve bu atıkların sağlık ve beslenme yönüyle insan sağlığına kazandırdığı avantajları araştırmaktır. Çalışmada 11 meyve ve 9 sebzenin genellikle mutfakta atık olarak düşünülen sap, gövde, kabuk gibi kısımlarından 20 farklı tarif geliştirilmiş ve bu tariflerin besin değerleri BEBİS programı (Beslenme Bilgi Sistemi) kullanılarak hesaplanmıştır. Ayrıca çalışmada kullanılan meyve ve sebze atıklarının fonksiyonel özellikleri bilimsel literatür ışığında irdelenmiştir. Sonuç olarak, atık olarak görülen meyve ve sebze kısımlarının beslenme açısından değerli özellikler olan; iyi bir diyet lifi, antioksidan, vitamin ve mineral kaynağı olduğu belirlenmiştir. Çalışma kapsamında meyve atıkları ile oluşturulan tarifler arasında en yüksek enerji değerine sahip ürün nar kabuğu tozlu çikolatalı toplar (4255.3 kcal), en yüksek protein portakal aromalı tatlı tavuk (122.1 g) ve en yüksek lif karpuzlama (25.3 g) olurken, sebze atıkları ile oluşturulan tarifler arasında en yüksek enerji değerine sahip ürün pırasa yapraklı milföy böreği (2740 kcal), en yüksek protein (222.2 g) ve lif (184.1 g) içeren karnabaharlı patatesli tuzlu kek olmuştur. Yiyeceklerde gıda atığı olarak görülen sap, kabuk, yaprak vb. kısımlarının kullanımı aynı zamanda yapılan tariflere fonksiyonel özellikler kazandırmaktadır. Bu çalışmada kullanılan gıda atıklarının literatürde antikanser, antimikrobiyal, antiviral, antiimflamatuar, nörolojik bozuklukları önleme, obezite diyabet ve yaşlanma karşıtı gibi özelliklere sahip olduğu görülmüştür.

Anahtar Kelimeler: Gıda atığı, Sebze, Meyve, Fonksiyonel gıda, Gastronomi

INTRODUCTION

Food waste includes foods purchased by consumers, restaurants and food and beverage manufacturers, but not consumed by customers in businesses and individuals at home [1]. Food waste is decomposable organic substances of animal and vegetable origin resulting from food service, cooking, preparation, sale, storage and transportation [2]. Edible food waste refers to unused, damaged products and foods that can be eaten before being thrown away [3]. The problems caused by food waste can be addressed in two dimensions. The first of these include inability to use resources economically, efficiently and effectively; increasing poverty in the world, facing hunger and deteriorating socio-economic situation [4]. Another problem caused by food waste takes place at an ecological level. Food waste causes an increase in greenhouse gas emissions released into nature and wasteful use of soil and water. [5].

Every day, one in eight people in the world goes to bed hungry, and more than 20,000 children die due to malnutrition and hunger. The FAO estimates that one-third of the world's food production is lost or wasted. If even one-quarter of the food wasted or lost globally were saved, 840 million hungry people could be fed [6, 7]. Every year, 198 million hectares of land are used to grow wasted food, representing 173 billion cubic meters of wasted water. Additionally, the time and labor wasted in the production, transportation, and marketing of foodstuffs also contribute to these losses [5]. Studies report that annual food waste in Turkey is 26 million tons, with fruits and vegetables ranking first among wasted foods [8, 9]. It is known that, in our country, fruits and vegetables suffer from 10-50% food loss due to mistakes made during and after harvest, depending on the variety and species. While this rate is higher in underdeveloped countries, it is lower in developed countries [10]. Many countries and international organizations are working against food waste to prevent negative outcomes such as environmental pollution, poor resource use, social injustice, disruption of ecological balance, and climate change caused by food waste [11]. In his study on sustainability, Gülsöz [12] determined that most vegetables and fruits have a low environmental impact; however, hard fruits (e.g., apples) and root and tuber vegetables are resistant to spoilage and, therefore, have lower greenhouse gas emissions than sensitive vegetables and fruits (e.g., strawberries, cucumbers).

Some of the advantages of creating new recipes from food waste, as reported in the literature, are as follows: increasing the nutritional value of the recipe to which it is added [13-15], providing dietary fiber and reducing the glycemic index [16, 17], and increasing the phenolic compound content [18-21]. Additionally, the compounds contained in food waste have been found to help prevent neurodegenerative diseases and cancer [22], regulate the body's metabolic activities [16, 23], and help prevent and fight obesity and diabetes [24, 25]. Furthermore, scientific literature reports that garden cress seed flour and tangerine peel powder can be used to enhance the nutritional and physical properties of cakes [26]. Cauliflower leaf powder can enrich cookies [27], some food waste can be used in the production of sherbet [28], and using banana peel powder instead of wheat flour in cakes has been found to have antimicrobial properties and positive effects on antioxidant and nutritional value [29]. It has also been reported that dried watermelon peel extract has functional and nutritional properties, including vitamin and mineral content [30]. Similarly, the amount of phenolic substances in apples varies across different parts, with the highest amount of total phenolic substances located in the apple peel [31]. The total phenolics, essential phenolics, and ascorbic acid content in orange, grapefruit, and lemon peels are higher than in the peeled parts of the fruit. It has been found that the total polyphenol and iron content in lemon peels are significantly higher than those in peeled oranges, grapefruits, and their peels [32].

Fruits and vegetables, as one of the most important food groups in people's daily diets, hold great significance for health and nutrition. Today, there are numerous studies on food waste, nutrition, and sustainability. Unlike other branches of science, gastronomy can offer a more active solution to the waste problem locally and within food businesses. In this context, practical studies aimed at preventing waste are of great importance. In this study, recipes were created by utilizing the waste parts of fruits and vegetables, such as peels, stems, or leaves, with the aim of reducing kitchen food waste and incorporating these parts into human nutrition. Additionally, another goal of this study is to highlight the nutritional and health importance of the wasted parts of vegetables and fruits.

MATERIALS and METHODS

This study was primarily a research and application attempt, carried out in three stages. First, a literature review was conducted to identify food waste components suitable for use in the application study. The second stage involved identifying products frequently encountered as food waste that could be used in recipe creation based on the obtained data. In the first stage, keywords such as "food waste, recipes made from food waste, nutritional value potential of food waste in general, negative effects of food waste" were used to select studies relevant to the general framework of our research. In the second stage, new recipes were designed using seasonal fruits and vegetables, incorporating unused parts like peels, roots, and leaves. These recipes were repeated an average of 2-3 times to identify and standardize the successful ones.

For the third stage, the BEBIS 9 (Nutrition Information System) program was used to analyze the nutritional values of the designed recipes. A literature review was conducted to gather nutritional data (carbohydrates, fat, protein, water, minerals, and vitamins) for parts like peels and stems, which are not included in BEBIS, using resources within seasonal and local constraints. The nutritional values of the standardized recipes were subsequently calculated using the BEBIS program. Furthermore, searches for studies on the functional properties and health benefits of the vegetables and fruits used in our recipes were conducted using YÖKTEZ, Google Scholar, PubMed, and Science Direct databases. Keywords included the names and nutritional values of the specific products used in the recipes (e.g., "cucumber peel and its nutritional value"). Details of all research stages are presented in the accompanying table (Table 1).

Table 1. Details about the research

Research Basic Steps	Themes	Titles Presented
Document analysis	Key words: General Turkish and English theses and articles on "food waste, food waste, environmental/health effects of food waste"	Introduction
Product Design from Fruit and Vegetable Waste	Recipes were created from seasonal vegetables and fruits, successful recipes were identified and standardized with an average of 2-3 repetitions.	Results/Recipes Created from Vegetable and Fruit Waste
Nutritional Value Calculation (BEBIS)	Turkish and English keywords regarding nutritional values were used for each vegetable and fruit used in the recipes.	Results/Recipes Created from Vegetable and Fruit Waste
Literature Review on Functional Features of Recipes	Key Words: vegetable/fruit Latin name and nutritional value, vitamin, mineral, chemical content	Results/General Functional Properties of Recipes Composed of Vegetables and Fruits

RESULTS and DISCUSSION

Zero Waste Recipes Developed to Reduce Vegetable Waste

Puff Pastry with Leek Leaf

The recipe for leek leaf and puff pastry involves the following ingredients: 70 g of the leaf part of the leek, the green part of 3 stalks of leek, 350 g of potato (2 medium-sized), 75 g of onion (1 small-sized), 60 mL of olive oil (5 tablespoons), 490 g of puff pastry (7 pieces), 18 g of egg yolk (1 piece), 100 mL of water (½ cup), 10 g of salt (2 teaspoons), 1 g of black pepper (½ teaspoon), and 4 g of red pepper flakes (1 teaspoon).

Onions and oil were added to the pan and sautéed until the onions slightly changed color. When this happened, finely chopped leeks were added. The mixture was stirred for 2-3 minutes before grated potatoes were added. The ingredients were mixed for a few more minutes, then 1 tea glass of water and spices were added. Once the vegetables absorbed the water, they were removed from the stove. The puff pastry, which had been taken out of the freezer to thaw, was placed on a rectangular tray measuring 40x27 cm lined with wax paper. Four pieces of puff pastry were rolled out with a rolling pin or by hand and placed on the bottom of the tray, extending 3-4 cm over both edges. One and a half puff pastry sheets were placed on each long side of the rectangular tray, and the pieces were pressed together to seal. Small holes were pricked in the puff pastry with a fork to prevent it from rising too much. The prepared mixture was added to cover the bottom of the tray. The puff pastry sheets hanging from the edge of the tray were folded over the mixture. The top was brushed with egg yolk and baked in the oven at 200°C for 25-30 minutes. The dish was allowed to cool slightly before serving.

The BEBIS analysis results were as follows: The total energy content was 2740.2 kcal, with each slice containing 182.68 kcal. The pastry contained 675.5 g of water, 40.6 g of protein (6%), 181.4 g of fat (59%), and 236.9 g of carbohydrates (35%). It also included 19.4 g of fiber, 59.5 g of polyunsaturated fatty acids, and 227.4 mg of cholesterol. In terms of vitamins, the pastry provided 1144.6 µg of vitamin A, 1.0 mg of carotene, 13.5 mg of vitamin E, 1.4 mg of vitamin B1 (thiamine), 0.4 mg of vitamin B2 (riboflavin), 1.3 mg of vitamin B6 (pyridoxine), 248.1 µg of total folate, and 111.8 mg of vitamin C. The mineral content included 5045.0 mg of sodium, 2102.4 mg of potassium, 4391 mg of calcium, 176.3 mg of magnesium, 564.8 mg of phosphorus, 10.0 mg of iron, and 4.4 mg of zinc.

Cauliflower and Potato Salted Cake

The recipe included the following ingredients: 250 g of cauliflower root (1 large cauliflower root), 100 g of cauliflower leaf (5-6 branches), 180 g of chicken egg (raw, 3 pieces), 220 g of potato (raw, without skin, 1 medium size), 50 g of cheddar cheese condiment (1 tea cup), 220 g of wheat flour (2 cups), 10 g of baking powder (1 pack), 100 mL of olive oil seasoning (1 tea glass), 245 g of full-fat yogurt (1 glass), 16 g of table salt (iodized, 1 tablespoon), 2 g of red pepper powder (1 teaspoon), and 1 g of black pepper (1 teaspoon).

The flower parts of the cauliflower were separated. The remaining root part was washed and cleaned, then reduced by processing it through a food processor. The leaf part of the cauliflower was finely chopped. Eggs and salt were placed in a bowl and whisked until they turned white. Olive oil, yogurt, flour, baking powder, and spices were added and whisked until the ingredients were combined. Cauliflower root, leaves, grated potato, and grated cheddar cheese were then added and mixed. A 28x28 cm Pyrex tray was greased, and the mixture was added. It was baked in a preheated oven at 200°C for 45-50 minutes. Once browned, it was taken out of the oven and served.

The BEBIS analysis results were as follows: The total energy content was 2401.2 kcal, with each slice containing 150.07 kcal. The cake contained 581.8 g of water, 222.2 g of protein (15%), 140.3 g of fat (21%), and 959.7 g of carbohydrates (65%). It also included 184.1 g of fiber, 13.7 g of polyunsaturated fatty acids, and 813.9 mg of cholesterol. In terms of vitamins, the cake provided 783.1 µg of vitamin A, 1.1 mg of carotene, 16.5 mg of vitamin E, 0.7 mg of vitamin B1, 1.6 mg of vitamin B2, 0.7 mg of vitamin B6, 173.1 µg of total folate, and 43.7 mg of vitamin C. The mineral content included 10,147.6 mg of sodium, 14,227.3 mg of potassium, 2,994.5 mg of calcium, 519.5 mg of magnesium, 2,818.6 mg of phosphorus, 135.0 mg of iron, and 89.4 mg of zinc.

Creamy Carrot Peel Soup

The recipe included the following ingredients: 120 g of carrot peel, 15 g of butter (1 tablespoon), 8 g of raw garlic (2 cloves), 40 g of cream (30% fat, 4 tablespoons), 20 g of wheat flour (2 tablespoons), 1200 mL of drinking water (6 cups), 10 g of iodized table salt (2 teaspoons), 2 g of black pepper (1 teaspoon), and 1 g of dry turmeric (½ teaspoon).

In this soup recipe, the butter was melted in a pot, and 2 tablespoons of flour were added, roasting until the flour smell disappeared. Hot water, chopped carrot peels, garlic, and spices were then added and cooked until it boiled. The cream was added and boiled for another 15 minutes. After removing it from the stove, the mixture was blended to achieve a smooth consistency. This recipe made 4 portions of soup. Additionally, carrot peels that were peeled at different times could be kept in the freezer for future soup-making.

The BEBIS analysis results for the creamy carrot peel soup were as follows: The total energy content was 321.8 kcal, with each portion containing 80.45 kcal. The soup contained 1235.0 g of water, 3.8 g of protein (5%), 25.5 g of fat (71%), and 19.2 g of carbohydrates (24%). It also included 1.0 g of fiber, 0.7 g of polyunsaturated fatty acids, and 66.8 mg of cholesterol. In terms of vitamins, the soup provided 236.3 µg of vitamin A, 0.1 mg of carotene, 0.6 mg of vitamin E, 0.0 mg of vitamin B1, 0.1 mg of vitamin B2, 0.1 mg of vitamin B6, 5.2 µg of total folate, and 1.5 mg of vitamin C. The mineral content included 3941.9 mg of sodium, 148.8 mg of potassium, 173.6 mg of calcium, 58.2 mg of magnesium, 69.9 mg of phosphorus, 5.7 mg of iron, and 4.1 mg of zinc.

Pastry with Radish Leaves

The recipe included the following ingredients: 120 g of radish leaf, 50 g of onion (1 small size), 4 g of raw garlic (1 clove), 30 g of olive oil seasoning (3 tablespoons), 55 g of wheat flour (1 tea glass), 16 g of wheat starch (2 tablespoons), 1 g of baking powder (½ teaspoon), and 5 g of iodized table salt (1 teaspoon).

The radish leaves were washed thoroughly and chopped into small pieces. Oil and onion, chopped into small cubes, were added to the pot. After the onions were roasted, radish leaves and garlic were added. The radish leaves were cooked until they released their water. If there was excess water after cooling, it was squeezed out with the help of cheesecloth. In a separate bowl, flour, starch, baking powder, spices, and the cooked and squeezed radish leaves were added and kneaded. Approximately 15 balls the size of a walnut were obtained. They were placed on a baking tray lined with baking paper and baked in a preheated oven at 180°C for about 40 minutes until golden brown. They were preferably served with garlic yogurt.

The BEBIS analysis results were as follows: The total energy content was 535.0 kcal, with each piece containing 35.6 kcal. The pastry contained 165.6 g of water, 11.2 g of protein (8%), 31.2 g of fat (48%), and 63.0 g of carbohydrates (44%). It also included 3.4 g of fiber, 3.1 g of polyunsaturated fatty acids, and 0.3 mg of cholesterol. In terms of vitamins, the pastry provided 47.8 µg of vitamin A, 0.1 mg of carotene, 3.7 mg of vitamin E, 0.1 mg of vitamin B1, 0.0 mg of vitamin B2, 0.1 mg of vitamin B6, 11.8 µg of total folate, and 4.3 mg of vitamin C. The mineral content included 2,422.7 mg of sodium, 805.7 mg of potassium, 946.8 mg of calcium, 91.5 mg of magnesium, 153.3 mg of phosphorus, 5.1 mg of iron, and 0.9 mg of zinc.

Crispy Potato Sticks with Potato Skins

The recipe included the following ingredients: 400 g of potato (raw, in shell, 2 pieces), 50 g of cheddar cheese, 5 g of iodized table salt (1 teaspoon), 1 g of black pepper, 2 g of hot/shark pepper powder (½ teaspoon), and 30 mL of olive oil seasoning (3 tablespoons).

The minced meat was placed in a pot and roasted over low heat. After it changed color, 3 tablespoons of oil were added. Onion, green pepper, and finely chopped eggplant peels were added and mixed. Once the vegetables were roasted, tomatoes and spices were added and cooked. The lavash bread was divided in half, and 1 tablespoon of the mixture was placed at the tip. Some grated cheddar cheese was added to cover the mixture. The edges of the lavash bread were folded inward to form a triangle. It was put in the toaster, with oil spread on it, and baked until both sides of the lavash were golden brown. This recipe yielded 10 lavash toasts.
The BEBIS analysis results were as follows: The total energy content was 456.1 kcal, with each piece containing 28.5 kcal. The dish contained 272.8 g of water, 16.1 g of protein (15%), 19.7 g of fat (39%), and 51.5 g of carbohydrates (47%). It also included 4.6 g of fiber, 0.8 g

of polyunsaturated fatty acids, and 45.0 mg of cholesterol. In terms of vitamins, the dish provided 267.9 µg of vitamin A, 0.3 mg of carotene, 1.2 mg of vitamin E, 0.3 mg of vitamin B1, 0.2 mg of vitamin B2, 0.6 mg of vitamin B6, 74.3 µg of total folate, and 71.9 mg of vitamin C. The mineral content included 2,380.8 mg of sodium, 1,314.1 mg of potassium, 346.7 mg of calcium, 103.6 mg of magnesium, 314.2 mg of phosphorus, 3.3 mg of iron, and 2.9 mg of zinc.

Lavash Toast with Eggplant Peels

The recipe included the following ingredients: 350 g of lavash bread/flatbread (5 pieces), 150 g of eggplant skin, 40 mL of olive oil seasoning (4 tablespoons), 80 g of onion (1 medium size), 35 g of green/bell pepper (1 medium size), 90 g of raw tomato (1 small size), 100 g of raw minced beef, 100 g of cheddar cheese, 5 g of hot pepper paste with tomato (1 teaspoon), 4 g of iodized table salt, and 2 g of black pepper.

The minced meat was placed in a pot and roasted over low heat. After it changed color, 3 tablespoons of oil were added. Onion, green pepper, and finely chopped eggplant peels were added and mixed. Once the vegetables were roasted, tomatoes and spices were added and cooked. The lavash bread was divided in half, and 1 tablespoon of the cooked mixture was added to the tip. Some grated cheddar cheese was placed over the mixture. The edges of the lavash bread were folded inward to form a triangle. It was put in the toaster, with oil spread on it, and baked until both sides of the lavash were golden brown. This recipe made 10 lavash toasts.

The BEBIS analysis results were as follows: The total energy content was 1926.9 kcal, with each piece containing 192.6 kcal. The dish contained 423.5 g of water, 72.3 g of protein (15%), 98.2 g of fat (45%), and 188.9 g of carbohydrates (40%). It also included 19.6 g of fiber, 7.4 g of polyunsaturated fatty acids, and 153.9 mg of cholesterol. In terms of vitamins, the dish provided 696.0 µg of vitamin A, 1.1 mg of carotene, 9.5 mg of vitamin E, 0.5 mg of vitamin B1, 0.9 mg of vitamin B2, 0.7 mg of vitamin B6, 183.1 µg of total folate, and 65.2 mg of vitamin C. The mineral content included 4,382.9 mg of sodium, 1,577.6 mg of potassium, 872.0 mg of calcium, 211.3 mg of magnesium, 1,008.2 mg of phosphorus, 6.4 mg of iron, and 11.0 mg of zinc.

Breakfast Appetizer with Cucumber Peel

The recipe includes the following ingredients: 90 g of white cheese condiment, 1 g of coriander root (1 teaspoon), 15 mL of olive oil seasoning (1 and a half tablespoons), 1 g of red pepper (1 teaspoon), and 30 g of cucumber peel (from 1 cucumber).

Cucumber peels were ground with a hand processor. Cheese, coriander powder, chili pepper, and olive oil were added and processed through a food processor. The mixture was placed on a serving plate and consumed for breakfast. The ingredients made 2 portions of a breakfast appetizer.

BEBIS results were as follows: The total energy content of the breakfast appetizer with cucumber peel was 461.3 kcal, and the energy in one portion was 230.6 kcal. It contained 49.2 g of water, 14.6 g of protein (14% of energy), 35.2 g of fat (73% of energy), and 14.2 g of carbohydrates (14% of energy). The fiber content was 2.9 g, with 2.2 g of polyunsaturated fatty acids and 48.8 mg of cholesterol. It also included 351.8 µg of vitamin A, 0.5 mg of carotene, 2.1 mg of vitamin E, 0.0 mg of vitamin B1, 0.4 mg of vitamin B2, 0.2 mg of vitamin B6, 45.0 µg of total folate, and 0.3 mg of vitamin C. The mineral content included 934.4 mg of sodium, 294.8 mg of potassium, 412.5 mg of calcium, 39.3 mg of magnesium, 363.8 mg of phosphorus, 2.8 mg of iron, and 3.5 mg of zinc.

Red Beetroot Peel Tarator

The recipe included 120 g of red beetroot peel (equivalent to 5 medium-sized beetroots), 20 mL of olive oil seasoning (2 tablespoons), 8 g of table salt (iodized, 1 teaspoon), 250 g of full-fat yogurt (1 bowl), 4 g of raw garlic (1 clove), and 10 g of walnuts (2 pieces).

The red beets were thoroughly washed and peeled. The peeled beetroot skins were cut into small pieces using a food processor. They were then placed in a pan and fried with 2 tablespoons of olive oil. One teaspoon of salt was added. Separately, yogurt was mixed with 1 crushed clove of garlic in a bowl. This mixture was combined with the roasted red beetroot peel. The dish was served topped with coarsely ground walnuts. The ingredients made 3 portions of this appetizer. Once peeled, the beets could be stored in the freezer for future use in this recipe.

BEBIS results were as follows: The total energy content of the red beetroot peel dish was 478.4 kcal, with one portion containing 159.4 kcal. It had 218.8 g of water, 11.5 g of protein (11% of energy), 36.4 g of fat (77% of energy), and 12.7 g of carbohydrates (12% of energy). The fiber content was 0.5 g, with 7.4 g of polyunsaturated fatty acids and 25.2 mg of cholesterol. The vitamin content included 111.8 µg of vitamin A, 0.1 mg of carotene, 5.1 mg of vitamin E, 0.1 mg of vitamin B1, 0.5 mg of vitamin B2, 0.2 mg of vitamin B6, 33.1 µg of total folate, and 3.1 mg of vitamin C. The mineral content included 3234.0 mg of sodium, 475.2 mg of potassium, 330.2 mg of calcium, 62.3 mg of magnesium, 293.6 mg of phosphorus, 32.2 mg of iron, and 1.4 mg of zinc.

Tomato Crusted Cracker

The recipe included 200 g of tomato peel, 220 g of wheat flour (equivalent to 2 cups), 80 g of black olives (about 20 pieces), 10 g of black cumin (1 tablespoon), 10 mL of olive oil seasoning (1 tablespoon), 4 g of dried thyme (1 teaspoon), 4 g of hot/sharp pepper powder (1 teaspoon), and 8 g of iodized table salt (1 teaspoon).

The tomato peels and olives were processed in a food processor until finely ground. The mixture was placed in a kneading bowl, and the other ingredients were added. By kneading, a dough of non-sticky consistency was formed. The dough was then baked in the oven at 180°C for 15-20 minutes. The ingredients yielded approximately 20 crackers. If the tomatoes are not used immediately after peeling, they can be stored in the freezer for later use. Additionally, when making canned tomatoes, the peeled tomato skins can be utilized in this recipe.

The BEBIS analysis results were as follows: The total energy content was 995.1 kcal, with each portion containing 49.75 kcal. The crackers contained 92.2 g of water, 46.8 g of protein (11%), 32.4 g of fat (16%), and 326.0 g of carbohydrates (74%). They also included 12.1 g of fiber, 4.8 g of polyunsaturated fatty acids, and 0.1 mg of cholesterol. In terms of vitamins, the crackers provided 95.9 µg of vitamin A, 0.5 mg of carotene, 3.0 mg of vitamin E, 0.4 mg of vitamin B1, 0.2 mg of vitamin B2, 0.2 mg of vitamin B6, 67.3 µg of total folate, and 23.8 mg of vitamin C. The mineral content included 4,942.2 mg of sodium, 2,697.5 mg of potassium, 513.0 mg of calcium, 365.4 mg of magnesium, 242.4 mg of phosphorus, 11.8 mg of iron, and 8.4 mg of zinc.

Zero Waste Recipes Developed to Reduce Fruit Waste

Baked Halva with Tangerine

The recipe included the following ingredients: 150 g of tahini halva, 50 mL of milk (¼ cup), 10 g of grated tangerine peel (1 tablespoon), and 15 g of raw almonds (approximately 15 pieces).

The halva was cut into cubes and placed in a bowl. It was then crushed with a fork, and milk was added to help melt the halva. A tablespoon of tangerine zest and coarsely ground raw almonds were added and mixed in. The mixture was divided among soufflé bowls. It was baked in the oven at 180°C until golden brown. This recipe yielded two portions of baked halva.

The BEBIS analysis results were as follows: The total energy content was 780.7 kcal, with each portion containing 390.35 kcal. The dish contained 44.3 g of water, 20.8 g of protein (10%), 41.9 g of fat (46%), and 88.1 g of carbohydrates (44%). It also included 7.6 g of fiber, 15.7 g of polyunsaturated fatty acids, and 5.0 mg of cholesterol. In terms of vitamins, the dish provided 23.5 µg of vitamin A, 0.0 mg of carotene, 5.4 mg of vitamin E, 0.5 mg of vitamin B1, 0.2 mg of vitamin B2, 0.1 mg of vitamin B6, 65.8 µg of total folate, and 0.6 mg of vitamin C. The mineral content included 48.8 mg of sodium, 412.4 mg of potassium, 151.8 mg of calcium, 241.2 mg of magnesium, 555.0 mg of phosphorus, 5.1 mg of iron, and 6.7 mg of zinc.

Lemon Zest and Pistachio Custard

The recipe includes the following ingredients: 600 mL of full-fat cow's milk (3 cups), 20 g of corn starch (1.5 tablespoons), 25 g of wheat flour (2 tablespoons), 80 g of sugar (½ cup), 20 g of pistachios (without shells, 2 tablespoons), 20 g of lemon peel (2 tablespoons), 2.5 g of vanillin sugar or vanilla (½ pack), and 5 g of butter (1 teaspoon).

To prepare the pudding, the milk, flour, starch, sugar, and previously dried and ground lemon peel were combined in a pot. The mixture was cooked over medium heat, with continuous stirring, until it thickened. Care was taken not to overcook or let the mixture brown, ensuring a smooth pudding texture. As the mixture began to thicken, the heat was reduced to low for better control. Once the pudding had thickened to the desired consistency, the heat was turned off. The sugared vanilla, butter, and ground pistachios were added and stirred well to combine all the ingredients thoroughly. The pudding was poured into serving plates and allowed to cool in the refrigerator. This recipe made approximately 3 portions of pudding.

The BEBIS analysis results were as follows: The total energy content was 1035.5 kcal, with each portion containing 345.1 kcal. The pudding contained 531.7 g of water, 28.1 g of protein (11%), 36.6 g of fat (31%), and 148.1 g of carbohydrates (58%). It also included 15.0 g of fiber, 2.2 g of polyunsaturated fatty acids, and 65.1 mg of cholesterol. In terms of vitamins, the pudding provided 223.6 µg of vitamin A, 0.2 mg of carotene, 1.6 mg of vitamin E, 0.4 mg of vitamin B1, 1.1 mg of vitamin B2, 0.3 mg of vitamin B6, 68.1 µg of total folate, and 11.6 mg of vitamin C. The mineral content included 272.7 mg of sodium, 1,115.3 mg of potassium, 758.3 mg of calcium, 110.1 mg of magnesium, 679.3 mg of phosphorus, 2.4 mg of iron, and 3.4 mg of zinc.

Chocolate Balls with Pomegranate Peel Powder

The recipe included the following ingredients: 180 g (3 pieces) of raw chicken eggs, 160 g (1 cup) of sugar, 120 ml (slightly more than ½ cup) of olive oil seasoning, 200 ml (1 cup) of full-fat cow's milk, 10 g (1 pack) of baking powder, 5 g (1 pack) of vanillin sugar/vanilla, 220 g (2 cups) of wheat flour, 200 ml (1 pack) of cream (30% fat), 100 g (1 pack) of light dark chocolate, 40 g of hazelnuts, and 20 g (1 tea glass) of pomegranate peel powder.

The eggs and sugar were thoroughly whisked in a bowl. Then, milk, oil, and vanilla were added and whisked together. Following this, flour, pomegranate peel powder, and baking powder were mixed in. The mixture was poured into a greased tray and baked in a preheated oven at 180°C for 40-45 minutes. The baked cake was left to cool. For the topping, the cream was heated on the stove, with dark chocolate added to melt. Once cooled, the cream mixture and ground hazelnuts were kneaded into the cake. Walnut-sized circles were then formed. Optionally, these could be decorated with ingredients such as white chocolate, pistachios, hazelnuts, and coconut. The recipe yielded 30 truffles. Thanks to the added pomegranate peel powder, the fiber content and functional properties of the cake were increased.

The BEBIS analysis results were as follows: The total energy content was 4255.3 kcal, with each piece containing 141.8 kcal. The balls contained 473.1 g of water, 72.1 g of protein (7%), 266.9 g of fat (55%), and 405.8 g of carbohydrates (38%). They also included 22.1 g of fiber, 19.7 g of polyunsaturated fatty acids, and 949.6 mg of cholesterol. In terms of vitamins, the balls provided 1230.0 µg of vitamin A, 0.6 mg of carotene, 31.4 mg of vitamin E, 0.8 mg of vitamin B1, 1.7 mg of vitamin B2, 0.8 mg of vitamin B6, 184.6 µg of total folate, and 5.4 mg of vitamin C. The mineral content included 1702.0 mg of sodium, 2748.4 mg of potassium, 752.6 mg of calcium, 359.7 mg of magnesium, 2026.4 mg of phosphorus, 25.5 mg of iron, and 8.5 mg of zinc.

Mini Pie with Apple Peels

The recipe included the following ingredients: 70 g of apple peel (from 2 medium-sized apples), 120 g of raw chicken eggs (2 pieces), 30 g of sugar (slightly more than 1 tea glass), 200 mL of full-fat cow's milk (1 tea glass), 330 g of wheat flour (3 glasses), 10 g of baking powder (1 piece), 5 g of vanillin sugar or vanilla (½ tea cup), 5 g of cinnamon (2 tablespoons), 50 mL of drinking water (3 tablespoons), and 3 g of olive oil condiment (1 heaping tablespoon).

The apple peels that had been peeled beforehand were not thrown away but kept in the deep freezer. For this recipe, 2 medium-sized apples were also peeled. Any missing amount of peels was supplemented with the peels from the freezer. After the apples were grated and the peels chopped into small pieces, they were cooked in a pan on the stove. Sugar was added, and the mixture was cooked over medium heat until the apples released their juice. When the consistency of the apples was neither too dry nor too watery, the heat was turned off. Cinnamon and walnuts were added and mixed in.

To make the tart dough, room temperature eggs, butter, oil, and yogurt were added into a bowl and mixed until creamy. Powdered sugar, starch, baking powder, and vanilla were then added and mixed in. Three cups of flour were added, and the dough was kneaded. Additional flour could be added depending on the dough's consistency, which should be soft and non-sticky.

The dough was shaped into small round balls and placed in greased muffin molds to form a thin bottom layer. The stuffing mixture was added inside. The remaining dough was rolled out with a rolling pin to a thickness of 1 cm and cut into thin strips. These strips were placed on the muffin molds in a wicker pattern. The pies were baked in a preheated oven at 180°C until golden brown. Once cooled, they were served with a sprinkling of powdered sugar. The ingredients made 14 mini pies.

The BEBIS analysis results were as follows: The total energy content was 1637.2 kcal, with each portion containing 116.9 kcal. The pie contained 364.4 g of water, 57.8 g of protein (13%), 32.0 g of fat (15%), and 332.6 g of carbohydrates (72%). It also included 20.1 g of fiber, 3.6 g of polyunsaturated fatty acids, and 527.6 mg of cholesterol. In terms of vitamins, the pie provided 262.0 µg of vitamin A, 0.0 mg of carotene, 3.4 mg of vitamin E, 0.5 mg of vitamin B1, 1.0 mg of vitamin B2, 0.3 mg of vitamin B6, 103.4 µg of total folate, and 2.4 mg of vitamin C. The mineral content included 1448.0 mg of sodium, 1034.6 mg of potassium, 516.5 mg of calcium, 88.8 mg of magnesium, 1476.3 mg of phosphorus, 24.1 mg of iron, and 5.1 mg of zinc.

Orange Flavored Sweet Chicken

The recipe included the following ingredients: 500 g of chicken breast (2 pieces), 8 g of raw garlic (2 cloves), 30 g of full-fat yogurt (2 tablespoons), 10 g of honey (1 tablespoon), 10 g of pomegranate concentrate (1 tablespoon), 20 g of grated orange peel (2 tablespoons), 10 g of wheat flour (1 tablespoon), 5 g of iodized table salt (1 teaspoon), 4 g of hot/green pepper powder (1 teaspoon), 4 g of dry thyme (1 teaspoon), 2 g of black pepper (1 teaspoon), and 40 g of olive oil seasoning (4 tablespoons).

The chicken was diced and placed in a bowl. Yogurt, honey, pomegranate syrup, orange zest, and spices were added. All ingredients were mixed well and marinated. The mixture was then left to rest in the refrigerator for at least two to three hours. Oil was added to the pan and heated. The marinated chicken from the refrigerator was then placed in the pan and cooked, turning occasionally, until both sides were done. The ingredients made 3 servings.

According to BEBIS results, the total energy content of the orange-flavored sweet chicken was 1040.5 kcal, with each portion containing approximately 346.8 kcal. The nutritional breakdown is as follows: Water 425.0 g, protein 122.1 g (48%), fat 45.4 g (39%), carbohydrates 34.0 g (13%), fiber 2.5 g, polyunsaturated fatty acids 4.8 g, cholesterol 313.4 mg, vitamin A 505.3 µg, carotene 1.9 mg, vitamin E 6.9 mg, vitamin B1 0.5 mg, vitamin B2 0.6 mg, vitamin B6 2.9 mg, total folate 64.0 µg, vitamin C 54.5 mg, sodium 2295.4 mg, potassium 1686.9 mg, calcium 246.1 mg, magnesium 173.0 mg, phosphorus 1136.6 mg, iron 11.7 mg, and zinc 6.1 mg.

Magnolia with Banana Peel

The recipe included the following ingredients: 1000 mL of full-fat cow's milk (1 pack), 185 g of banana (1 whole banana), 30 g of wheat flour (3 tablespoons), 30 g of wheat starch (3 tablespoons), 150 g of sugar (less than 1 cup), 20 g of chicken egg yolk (1 piece), 15 g of butter (1 tablespoon), 5 g of vanillin sugar or vanilla (1 pack), 131 g of oatmeal biscuits (1 pack), 30 g of hazelnuts (1 handful), and 40 g of banana peel (peel of 1 banana).

For the dessert cream, flour, starch, egg yolk, and sugar were put into a pot. Milk and banana peels were blended together until the peels were thoroughly ground. This banana and milk mixture was then added to the pot, and all ingredients were mixed. The mixture was cooked over medium heat until it boiled and thickened. After removing from heat, butter, sugar, and vanillin were added. The oatmeal biscuits and hazelnuts were processed in a food processor until they reached a flour-like consistency. The cooked cream, processed biscuits, and hazelnuts were layered in a glass or bowl and decorated. The dessert was left to rest in the refrigerator for at least 2-3 hours before consuming. This recipe yielded 5 portions of magnolia.

According to BEBIS results, the total energy content of the banana peel and magnolia dessert was 2524.4 kcal, with each portion containing approximately 504.8 kcal. The nutritional breakdown is as follows: Water 1010.4 g, protein 67.3 g (10%), fat 105.8 g (34%), carbohydrates 371.2 g (55%), fiber 10.6 g, polyunsaturated fatty acids 6.1 g, cholesterol 524.0 mg, vitamin A 835.7 µg, Carotene 0.4 mg, vitamin E 11.1 mg, vitamin B1 0.8 mg, vitamin B2 2.0 mg, vitamin B6 1.1 mg, total folate 176.6 µg, vitamin C 25.8 mg, sodium 667.4 mg, potassium 2596.6 mg, calcium 1367.3 mg, magnesium 289.3 mg, phosphorus 1567.1 mg, iron 39.8 mg, and zinc 22.0 mg.

Ice Cream with Ripe Bananas and Strawberries

The recipe included the following ingredients: 185 g of banana (1 medium-sized whole banana), 65 g of frozen strawberries (4 medium-sized), 25 g of sweet almonds (plucked, ½ tea glass), 100 mL of full-fat cow's milk (1 tea glass), 20 g of honey (1 tablespoon), and a teaspoon tip of dry turmeric.

All ingredients were added and processed in a blender. The mixture was then poured into ice cream molds and placed in the deep freezer. It was periodically removed and mixed, or put through an ice cream machine, to eliminate ice crystals. The ice cream was ready to be consumed after being kept in the freezer overnight.

According to BEBIS results, the total energy content of the ripe banana, strawberry, and ice cream mixture was 415.4 kcal, with each portion containing approximately 69.2 kcal. The nutritional breakdown is as follows: Water 244.7 g, protein 11.7 g (12%), fat 17.9 g (39%), carbohydrates 49.8 g (50%), fiber 5.9 g, polyunsaturated fatty acids 3.3 g, cholesterol 9.0 mg, Vitamin A 45.6 µg, carotene 0.1 mg, vitamin E 3.8 mg, Vitamin B1 0.1 mg, vitamin B2 0.3 mg, vitamin B6 0.6 mg, total folate 58.0 µg, vitamin C 46.8 mg, sodium 48.8 mg, potassium 890.9 mg, calcium 163.6 mg, magnesium 115.0 mg, phosphorus 228.1 mg, iron 2.0 mg, and zinc 1.5 mg.

Apple Cinnamon Pancake

The recipe included the following ingredients: 70 g of apple peel, 120 g of raw chicken eggs (2 pieces), 30 g of sugar (2 tablespoons), 200 mL of full-fat cow's milk (1 cup), 165 g of wheat flour (1.5 cups), 10 g of baking powder (1 packet), 5 g of vanillin sugar or vanilla (1 packet), 5 g of cinnamon (1 teaspoon), 50 mL of drinking water (½ tea glass), and 3 g of olive oil condiment (1 teaspoon).

To prepare the batter, eggs and sugar were added to a mixing bowl and whisked until foamy. The apple peels were blended with ½ glass of water and ground thoroughly, then added to the mixing bowl. Milk, vanilla, flour, baking powder, and cinnamon were also added and whisked together. A few drops of oil were applied to the bottom of a non-stick pan with the help of a brush. Using a tablespoon, the pancake mixture was poured into the pan and cooked on both sides. The plated pancakes could be served with powdered sugar, honey, molasses, or fruits. The ingredients yielded approximately 30 pancakes.

According to BEBIS results, the total energy content of the apple-cinnamon pancakes was 1070.5 kcal, with each pancake containing approximately 35.6 kcal. The nutritional breakdown is as follows: Water 342.0 g, Protein 41.2 g (13%), Fat 30.4 g (21%), Carbohydrates 213.3 g (66%), Fiber 15.5 g, Polyunsaturated fatty acids 2.9 g, Cholesterol 527.6 mg, Vitamin A 262.0 µg, Carotene 0.0 mg, Vitamin E 3.1 mg, Vitamin B1/Thiamine 0.4 mg, Vitamin B2/Riboflavin 1.0 mg, Vitamin B6/Pyridoxine 0.2 mg, Total Folate 86.9 µg, Vitamin C 2.4 mg, Sodium 1446.4 mg, Potassium 757.4 mg, Calcium 508.2 mg, Magnesium 65.7 mg, Phosphorus 1374.0 mg, Iron 23.2 mg, and Zinc 4.3 mg.

Recipe of the Watermelon Waste

The recipe included the following ingredients: 500 g of watermelon rind (3-4 slices), 100 g of boiled dried chickpeas (less than 1 cup), 100 g of low-fat beef, 20 g of olive oil seasoning (2 tablespoons), 7 g of sumac (1 tablespoon), 80 g of onion (1 small-sized onion), 5 g of hot pepper paste with tomato (1 teaspoon), 1000 mL of drinking water, 14 g of butter (1 tablespoon), 8 g of iodized table salt (1 teaspoon), and 3 g of dry mint (1 tablespoon).

To prepare, the green part of the watermelon peel was peeled thinly, and the white rinds were chopped into cubes. They were covered with water and boiled in a pressure cooker for about 15 minutes. Meanwhile, sumac was soaked in water in a bowl to create a syrupy mixture. In a separate pot, oil and cubed beef were added, and the meat was roasted. Chopped onion was added next, and once the onions became transparent, tomato paste and hot water were mixed in. The mixture was boiled for about 40 minutes to soften the meat. Boiled chickpeas and watermelon peels were then added and cooked for another 15 minutes. The sumac syrup was strained and added to the dish before turning off the stove.

In a small pan, butter was melted and mint was added, being careful not to burn the mint. This mint mixture was poured over the dish and mixed in. The recipe made approximately 4 servings.

According to BEBIS results, the total energy content of this watermelon waste recipe was 551.1 kcal, with each portion containing approximately 137.8 kcal. The nutritional breakdown is as follows: Water 215.5 g, protein 66.7 g (12%), fat 39.4 g (15%), carbohydrates 406.6 g (73%), fiber 25.3 g, polyunsaturated fatty acids 3.2 g, cholesterol 101.1 mg, vitamin A 185.1 µg, Carotene 0.4 mg, vitamin E 4.9 mg, vitamin B1 0.4 mg, vitamin B2 0.4 mg, vitamin B6 0.5 mg, total folate 86.8 µg, vitamin C 9.7 mg, sodium 3261.7 mg, potassium 830.6 mg, calcium 260.3 mg, magnesium 112.8 mg, phosphorus 1086.4 mg, iron 12.4 mg, and zinc 12.5 mg.

Watermelon Rind Cookies

The recipe included the following ingredients: 350 g of watermelon rind, 200 mL of drinking water (1 cup), 80 g of sugar (1 tea glass), 15 g of lemon (¼ lemon), 330 g of wheat flour (3 cups), 250 g of butter, 20 g of full-fat yogurt

(1 tablespoon), 1 g of baking powder (1 teaspoon), and 65 g of powdered sugar (1 coffee cup).

To prepare, the green skin on the outside of the watermelon rind was peeled thinly, leaving the white part which was chopped into small cubes. These cubes were placed into a pressure cooker, covered with water, and boiled for an additional 15 minutes after boiling. In a separate pot, 1 cup of water, a tea glass of sugar, and ¼ lemon were boiled together, then the boiled watermelon peels were added and cooked for another 20 minutes.

For the cookie dough, butter, yogurt, baking powder, and powdered sugar were put into a kneading bowl and mixed by hand. Flour was slowly added until a soft, non-sticky dough was formed. Stretch film was placed inside a lemon squeezer, and walnut-sized balls of dough were rolled out thinly around the lemon squeezer. The watermelon peel mixture was placed inside and covered with another piece of dough. The cookies were carefully removed with the help of the stretch film and placed on a tray lined with baking paper. They were baked in the oven at 170°C for about 20 minutes until light pink. Once warm, they were served with a sprinkle of powdered sugar. These quantities yielded approximately 30 cookies.

According to BEBIS results, the total energy content of the watermelon crust cookies was 3595.4 kcal, with each cookie containing approximately 119.8 kcal. The nutritional breakdown is as follows: Water 314.2 g, protein 60.7 g (5%), fat 213.2 g (39%), carbohydrates 655.8 g (56%), fiber 19.0 g, polyunsaturated fatty acids 6.0 g, cholesterol 554.5 mg, vitamin A 1639.1 µg, carotene 1.0 mg, vitamin E 5.7 mg, vitamin B1 0.4 mg, vg, vitamin C 8.3 mg, sodium 192.0 mg, potassium 659.5 mg, calcium 203.4 mg, magnesium 67.6 mg, phosphorus 835.5 mg, iron 6.9 mg, and zinc 7.0 mg.

Profiteroles with Pomegranate Peel Powder

The recipe included the following ingredients: 140 g of wheat flour (1 cup + 3 tablespoons), 240 g of raw chicken eggs (4 pieces), 125 g of butter, 200 g of drinking water (1 cup), 750 mL of cow's milk (1 cup), 120 g of sugar (1 and a half tea glasses), 5 g of vanillin sugar or vanilla (1 pack), 75 g of chocolate sauce (½ pack), and 5 g of pomegranate peel powder (1 teaspoon).

To start, butter and water were boiled together in a small pot. Once the butter melted, 1 glass of flour was added and fried for 2-3 minutes before turning off the stove. The mixture was left to cool for 15-20 minutes. Then, eggs were added one by one, mixing well after each addition. After all the eggs were incorporated, the mixture was rested for approximately 10 minutes. Using a spoon, walnut-sized pieces of dough were placed onto a tray lined with baking paper and baked in a preheated 180°C oven for about 40 minutes until browned.

For the profiterole cream, milk, 3 tablespoons of flour, pomegranate peel powder, sugar, and 1 egg were stirred together in a separate pot until boiling, then cooked for an additional 2-3 minutes before turning off the heat. Vanillin sugar was mixed in afterwards. The prepared cream was added to the dough using a piping bag, or by halving the profiteroles and filling them. The chocolate sauce was cooked with milk in a small pot and poured over the filled profiteroles. This recipe yielded approximately 20 profiteroles.

According to BEBIS results, the total energy content of the profiterole with added pomegranate peel powder was 3050.3 kcal, with each portion containing approximately 152.5 kcal. The nutritional breakdown is as follows: Water 1076.4 g, protein 79.3 g (11%), fat 162.5 g (47%), carbohydrates 316.8 g (42%), fiber 10.9 g, polyunsaturated fatty acids 7.0 g, cholesterol 1366.4 mg, vitamin A 1441.0 µg, carotene 0.6 mg, vitamin E 9.1 mg, vitamin B1 0.7 mg, vitamin B2 2.8 mg, vitamin B6 0.6 mg, total folate 191.3 µg, vitamin c 9.5 mg, sodium 811.5 mg, potassium 2636.4 mg, calcium 1233.1 mg, magnesium 279.9 mg, phosphorus 1546.8 mg, iron 17.5 mg, and zinc 9.1 mg.

General Functional Properties of Recipes Composed of Vegetables and Fruits

The concept of food waste, a global problem, is gaining more attention each day. Measures should be taken to address food waste [33]. While solutions are being sought for people who are malnourished and at risk of starvation worldwide, the negative impact on the ecosystem due to excessive production and high consumption, along with the threat of impending food crises, are among the main issues that need resolution. According to the Food Waste Report (2021) by the United Nations Environment Programme, a total of 931 million tons of food is wasted annually worldwide (United Nations Environment Programme (UNEP), 2021) [34]. While there are initiatives to reduce and prevent food waste, it is possible to recycle food waste through various methods and applications without destroying it [35].

In nine recipes created with vegetables, the peel parts of carrots, radishes, potatoes, eggplants, cucumbers, red beets, and tomatoes, the root parts of cauliflower, and the green parts of leeks were used. Most commonly used vegetables have antioxidant effects, providing foods with many important functions such as antitumor, anticancer, antimicrobial, and antiviral properties [36-43]. Some studies indicate that the peel part of vegetables is a richer source of vitamins, minerals, and antioxidants than the pulp [44, 45]. Some of the vegetables used have protective properties against cancer, heart diseases, atherosclerosis, and neurodegenerative diseases [46-48]. Additionally, some unused vegetable peels, leaves, or root parts are an important source of dietary fiber, contributing to digestive health and aiding in the management of obesity and diabetes [23, 49, 50]. The functional properties of some vegetables included in the recipes are as follows: leek leaves are protective against cancer, coronary heart diseases, and atherosclerosis [47]; cauliflower roots are anticarcinogenic and contain dietary fiber and antioxidant compounds [48, 49]; potato peels have high digestibility due to their vitamins, essential amino acids, protein, and dietary fiber [23]; cucumber peels are used in the treatment of various diseases such as cancer, neurological disorders, aging, and inflammation [49]; red beets have antioxidant, antimicrobial, antiviral, anti-inflammatory, and anticancer properties [51]; tomato peels contain antioxidants and are an excellent source of nutritional and secondary metabolite compounds, mineral matter, vitamins C and E, B-carotene, lycopene, flavonoids, organic acids, and phenolics [37, 38].

In eleven recipes created with fruits, the peel parts of tangerine, lemon, pomegranate, apple, banana, strawberry, orange, and watermelon were used. Since bananas and strawberries are fruits whose consumption decreases when ripe, a recipe utilizing these fruits was included in the study. Apple, banana, watermelon, and pomegranate were used in two recipes each. Most commonly used fruits contain phenolic acids and flavonoids, which have antioxidant properties and contribute to foods with antiviral, antimicrobial, antitumor, and anticancer functions [52-55]. Additionally, the unused parts of some fruit peels are an important source of dietary fiber, supporting digestive health and aiding in the management of obesity and diabetes [16, 17, 56]. Some studies indicate that the peel part of fruits is a richer source of vitamins and minerals than the fleshy part [13, 30, 58]. The functional properties of some fruits included in the recipes are as follows: banana peel is effective against diabetes, heart disease, and hypertension [57]; pomegranate peel is an antimutagenic and anticarcinogenic agent with antimicrobial properties [52, 57]; apple peel has effects against cardiovascular diseases and some cancers, lowers cholesterol levels, and reduces the risk of diabetes [25, 26]; watermelon peel contains more phosphorus, calcium, vitamins A and C, minerals, natural polyphenols, antioxidants, and is a source of carotenoids and lycopene with anticarcinogenic effects [21, 20, 30].

CONCLUSION

In our study, the aim was to evaluate a portion of food waste that typically remains unutilized in kitchens. The focus was on foods that could facilitate recipe applications and for which calorie calculation methodologies existed in the literature. A total of 20 distinct recipes were developed utilizing data from existing research. In developing these recipes, it wasn't necessary for all ingredients to consist solely of waste. However, suitable waste was selected and combined with products commonly found as waste in kitchens yet normally consumed. After preparing these recipes, their caloric content was calculated using the BEBİS Nutrition Information Program.

Among the vegetable waste recipes, the puff pastry with leek leaves had the highest energy value at 2740 kcal. In contrast, the cauliflower potato salted cake had the highest protein content (222.2 g) and fiber content (184.1 g). For the fruit waste recipes, chocolate balls with pomegranate peel powder had the highest energy value (4255.3 kcal), orange-flavored sweet chicken had the highest protein content (122.1 g), and the watermelon waste recipe had the highest fiber content (25.3 g). The health benefits of the recipes were interpreted based on literature reviews, evaluating their antioxidant, vitamin, antimicrobial, and anticancer properties, as identified in previous studies.

To ensure the recipes could be easily adopted by individuals at home as well as food industry professionals, standardization in measurements, using spoons, cups, mL, and grams, was implemented. This study, approached from a sustainable nutrition perspective, emphasized local accessibility of ingredients. It also aimed to integrate valuable raw materials like peels, stems, leaves, and ripe fruits into nutrition programs while preventing ecological harm caused by wasting these materials. Nutritional values calculated with the BEBİS Program were shared with each recipe to highlight their health benefits.

Conclusively, the recipes incorporated peel parts of tangerine, lemon, pomegranate, apple, banana, orange, and watermelon, as well as ripe bananas and strawberries. Among vegetables, the peel parts of leek, parsley, carrot, radish, potato, eggplant, cucumber, red beet, tomato, and the root of cauliflower were used. Each of apple, banana, and watermelon was featured in two separate recipes. The scientific literature underscores that these vegetable and fruit parts are rich sources of vitamins, minerals, and essential oils. They contain key nutrients and secondary metabolites, often with superior functional properties compared to consumed portions.

The study found that parts typically seen as waste offer higher health and nutritional benefits than conventional portions. Many fruits and vegetables featured in the research are abundant in phenolic acids and flavonoids. The herbal kitchen wastes used are valuable for their antioxidant, antiviral, antimicrobial, antitumor, anticancer, antidiabetes properties, and their role in preventing cardiovascular and neurodegenerative diseases. They contribute to anti-obesity efforts, protect overall health, supply the body with needed fluids due to their high water content, and strengthen the immune system. It is crucial to develop initiatives such as using food waste in new product designs in gastronomy and to educate gastronomy students on this vital subject.

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Review Paper / Derleme Makale

Impact of Climate Change on Agricultural Production and Food Security

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ABSTRACT

This comprehensive analysis provides a detailed examination of the impacts of climate change on the agricultural sector, offering sustainable solutions with the objective of ensuring global food security. The detrimental impact of climate change on agricultural production, including global warming, significant alterations in precipitation patterns, and extreme weather events, has been meticulously assessed, with careful consideration given to their potential consequences for future food supply and security. In this context, a number of critical strategies and policies have been proposed, including the strengthening of water management policies, the advancement of sustainable agricultural practices, the development of climate-resilient seeds, and the enhancement of agricultural technologies. Moreover, the imperative for international collaboration and shared accountability has been forcefully emphasised, underscoring the necessity of maintaining this pivotal issue at the forefront of the global agenda. It is evident that a comprehensive approach is essential for combating climate change and ensuring sustainable agricultural production. Sustainable solutions and international cooperation are vital for guaranteeing a reliable future food supply and food security. In this context, the implementation of the proposed strategies and policies represents a crucial step towards aligning the agricultural sector with future needs and effectively addressing climate change.

Keywords: Climate change, Food security, Food safety, Drought, Agricultural production

İklim Değişikliğinin Tarımsal Üretim ve Gıda Arz Güvenliğine Etkisi

ÖZ

İklim değişikliğinin tarım sektörü üzerindeki etkilerini derinlemesine ele alan bu kapsamlı analiz, küresel gıda güvenliğini teminat altına almak amacıyla sürdürülebilir çözüm önerileri sunmaktadır. Küresel ısınma, yağış desenlerindeki köklü değişiklikler ve aşırı hava olayları gibi iklim değişikliğinin tarımsal üretim üzerindeki yıkıcı etkileri titizlikle değerlendirilmiş, bu etkilerin gelecekteki gıda arzı ve güvenliği üzerindeki olası sonuçları dikkatle gözden geçirilmiştir. Bu bağlamda, su yönetimi politikalarının güçlendirilmesi, sürdürülebilir tarım uygulamalarının daha ileriye taşınması, iklime dayanıklı tohumların geliştirilmesi ve tarım teknolojilerinin iyileştirilmesi gibi kritik stratejiler ve politikalar ortaya konulmuştur. Ayrıca, uluslararası işbirliği ve ortak sorumluluğun zaruriyeti güçlü bir şekilde vurgulanmış, bu hayati meselenin küresel düzeyde sürekli olarak gündemde tutulmasının önemi üzerinde durulmuştur. Sonuç olarak, iklim değişikliği ile mücadele etmek ve sürdürülebilir tarımsal üretimi güvence altına almak için kapsamlı bir yaklaşımın kaçınılmaz olduğu net bir şekilde ortaya konulmuştur. Sürdürülebilir çözümler ve uluslararası işbirliği, gelecekteki gıda arzını ve güvenliğini temin etmek için vazgeçilmez birer unsurdur. Bu bağlamda, önerilen strateji ve politikaların hayata geçirilmesi, tarım sektörünü geleceğin ihtiyaçlarına uygun hale getirmek ve iklim değişikliği ile etkin bir şekilde mücadele etmek adına kritik bir adım teşkil etmektedir.

Anahtar Kelimeler: İklim değişikliği, Gıda güvenliği, Gıda güvencesi, Kuraklık, Tarımsal üretim

INTRODUCTION

Climate change is considered one of the greatest threats facing the world, and its effects are becoming increasingly evident. However, these impacts vary greatly depending on geographical regions, economic conditions, social structures and other factors. In particular, developing and underdeveloped countries, and the agricultural communities living in these regions, are among the groups most vulnerable to the effects of climate change [1].

Agricultural activities are a major target of climate change, and current research suggests that changes in this sector could significantly affect future food supplies. The northward shift of rain-fed agricultural areas and the decline in cereal production in these regions suggest profound changes in the agricultural sector. Productivity studies indicate that significant reductions in crop yields are expected, ranging from 10% to 50%. However, it is hoped that the implementation of adaptation measures will partially mitigate these declines [2].

In countries where agriculture is an important sector, such as Türkiye, various measures are being taken to cope with climate change. In particular, the drought of 2007 has served to heighten awareness of climate change in the country, leading to the implementation of important steps such as agricultural drought management by the Ministry of Agriculture and Forestry. Such management systems are regarded as crucial tools for mitigating the effects of natural disasters such as drought. However, agricultural production not only is affected by climate change but also contributes to an increase in greenhouse gas emissions. In Türkiye, a significant proportion of total greenhouse gas emissions in 2019 was attributed to agricultural activities. This indicates that agriculture is not only affected by climate change, but also contributes to it [3].

Global Warming and Its Causes: Traces of Climate Change

In recent years, the recorded increase in global surface temperatures has continued at an alarming rate. For the period 2011-2020, the average global surface temperature increase has been measured at 1.09°C. This represents a significant increase compared to previous centuries. The temperature increase on land has been particularly pronounced in comparison to the oceans, with an average increase of 1.59°C on land in comparison to 0.88°C in the oceans (Figure 1) [4].

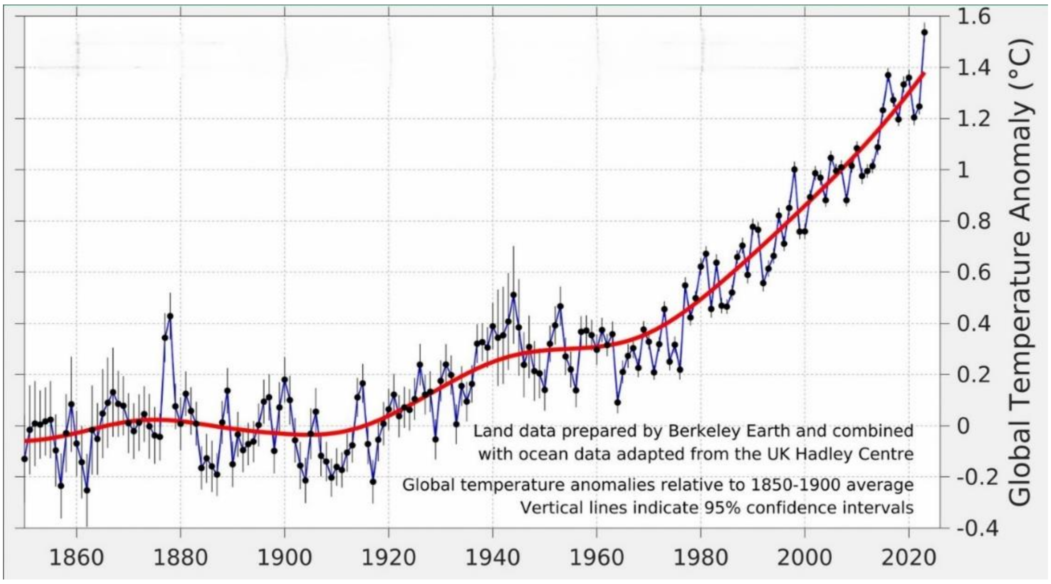

Figure 1. Global temperature increase from 1850 to 2023 [4]

At the beginning of the 21st century (2001-2020), the global surface temperature was observed to be 0.99°C higher than in the period 1850-1900. This increase is faster than any other 50-year period in the last 2000 years. Furthermore, the contribution of human activities to global warming has also been clearly demonstrated. From 1850-1900 to 2010-2019, the likely range of human-induced global surface temperature increase is estimated to be between 0.8°C and 1.3°C. The best estimate is 1.07°C. Over this period, greenhouse gases are likely to have contributed between 1.0°C and 2.0°C to the temperature increase. Furthermore, the effect of aerosols (air pollutants) has caused a natural cooling effect of between 0.0°C and 0.8°C (Figure 2) [5].

The projected increase in temperature is cause for concern. It is estimated that the temperature could reach 4°C by the year 2100. This would result in a significant increase in the problem of climate change, potentially tripling or quadrupling the current levels (Figure 3) [5].

The data presented here serve to illustrate the gravity of the climate change issue and the necessity for immediate and decisive action. International collaboration and the development of comprehensive policies are of paramount importance if we are to mitigate the effects of future global warming and ensure long-term sustainability.

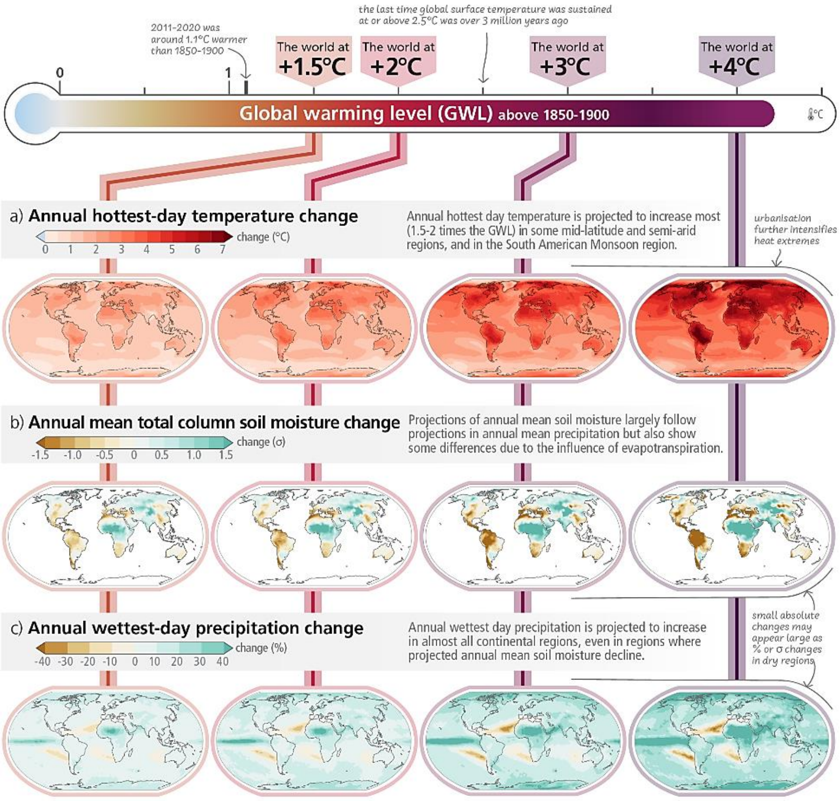

Figure 2. Global temperature increase [5]

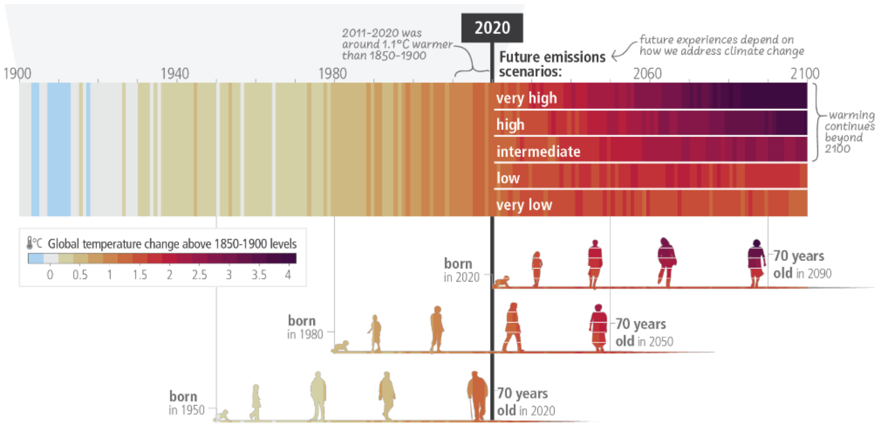

Figure 3. Future emissions scenarios [5]

Climate change and its impact on the agriculture and food sector

The agriculture and food sectors, which are considered to be strategic industries in the 21st century, are facing significant challenges as a result of a rapidly growing world population. The challenge of feeding a global population will place significant strain on current agricultural and food production capacities. Research indicates that to feed the world's population in 2050, agricultural and food production will need to be at least 50% higher than today [2, 6].

The challenges are further compounded by the effects of climate change. Projections indicate that climate change will increase water scarcity and droughts, reducing agricultural productivity. Globally, changes in precipitation patterns are expected to lead to some agricultural areas becoming drier, changes in crop maturation periods, and some agricultural land being inundated by floods or salinized by rising sea levels, reducing yields (Figure 4) [7]. Furthermore, rising temperatures have been observed to increase bacterial growth in food, which poses a serious threat to food safety [8].

It is anticipated that the effects of climate change will result in alterations to cropping areas and production patterns, which will in turn lead to a reduction in yields and a decline in production volumes. The consensus of leading experts and organizations is that agricultural productivity will decline by approximately 25% over the next 30 years [9].

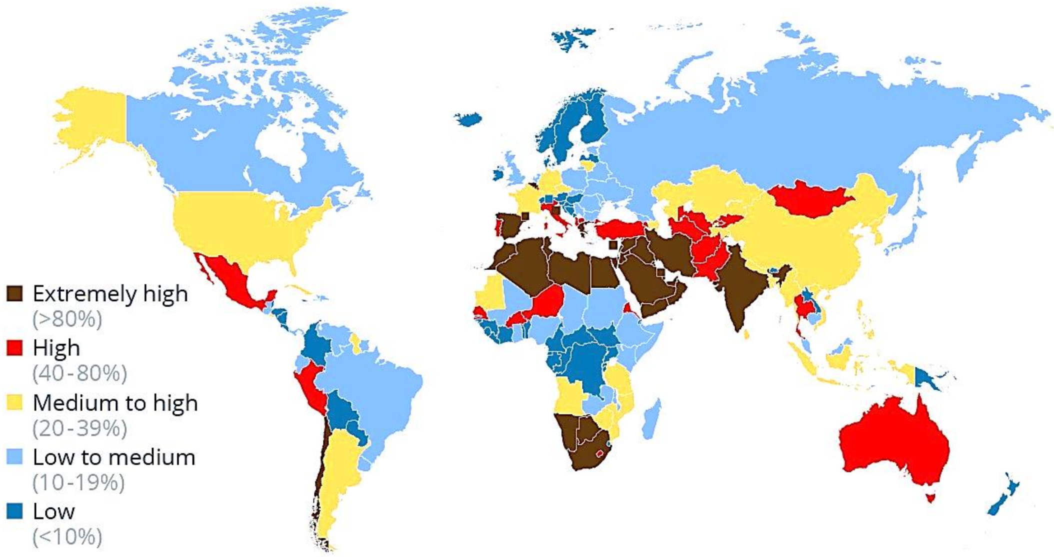

Figure 4. Water stress level sceneraio in 2050 [7]

In light of these impending challenges, it is imperative that the international community take immediate action. It is imperative that the agriculture and food sector be prepared for future challenges by implementing sustainable agricultural practices, strengthening water management policies, developing climate-resilient seeds and improving agricultural technologies. It is similarly imperative to reduce greenhouse gas emissions and intensify efforts to adapt to climate change [10].

Over the next decade, global food demand will be shaped by a complex interplay of factors. A number of factors will influence global food demand over the next decade, including population growth, climate change, advances in agricultural technologies, trade policies and global economic conditions [11].

Population growth will result in an increased global demand for food. It is estimated that the global population will exceed 10 billion by 2030. This will exert considerable pressure on food production and supply. In developing countries, in particular, population growth will result in a rapid increase in food demand [12].

Nevertheless, the consequences of climate change will also have a considerable impact on food production. The adverse effects of climate change, including rising temperatures, droughts, floods and natural disasters, can have a detrimental impact on agricultural productivity and production. This can result in a reduction in the area of arable land, a reduction in the quantity of available water, and a reduction in the yield of crops [13, 14].

Conversely, the advancement and innovation of agricultural technologies can enhance the productivity of food production, thereby facilitating the resolution of these challenges. The implementation of sustainable farming practices, the development of improved seeds, the implementation of enhanced irrigation systems and the utilization of digital farming technologies have the potential to significantly contribute to the ability to meet the growing demand for food [15].

Finally, trade policies and global economic conditions will also affect global food demand. Factors such as trade restrictions, tariffs and trade disputes can cause fluctuations in food supply and demand. Similarly, economic growth, income levels and consumer spending can affect food demand [16].

Taken together, these factors suggest that global food demand will continue to grow over the next decade. However, meeting this growing demand will require sustainable and innovative solutions. Investment in the agricultural sector, technological advances and international cooperation are critical to ensuring global food security [17].

In Türkiye due to 2022 data provided by TÜİK, cereal production is projected to increase by 21.3% compared to the previous year, reaching approximately 38.7 million tones. During this period, the self-sufficiency rate for total cereal production was estimated to be 80.3%. Wheat, which accounts for the largest share of cereal production, had a self-sufficiency rate of 87.3%. Different levels of self-sufficiency were observed for other cereal products. Among the pulses, chickpea production increased by 22.1% to 580 thousand tones, while red lentil production increased by 75.4% to 400 thousand tones. However, production of dry beans fell by 11.5% to 270 thousand tones [18].

The main scenario population projection by TÜİK for 2030 indicates that domestic red meat production is expected to rise from 2.191 million tons in 2022 to 2.436 million tons in 2030. Additionally, chicken egg production increased by 3.6%, and turkey meat production increased by 0.3%. However, chicken meat production decreased by 9.4%, and the number of slaughtered chickens decreased by 12.7%. These projections highlight the expected changes and current trends in the agricultural sector in the coming years. The data clearly emphasize the need for agricultural policies and production strategies to be appropriately shaped to meet future needs [19].

Sustainable Solutions for Agricultural Production and Food Supply

A number of goals and strategies have been identified with a view to adapting to climate change and making agricultural production sustainable. In this context, it is recommended that steps be taken to promote crop varieties that are suitable for the climate and water availability in agricultural basins, to complete land consolidation efforts, and to expand irrigated areas. Additionally, it is necessary to increase awareness and to accelerate grassland improvement efforts in order to combat erosion, desertification, and drought [20]. It is also important to consider the economic, social, and environmental impacts of agriculture and to support the use of environmentally friendly agricultural techniques. Furthermore, it is necessary to increase research at local, regional, and national levels and to identify high-risk areas [21].

Action plans should be developed in the agricultural sector to adapt to climate change, and capacity-building efforts should be carried out at various levels. In addition, it is important to establish early warning systems for agricultural and pasture areas, to conduct national land use planning, and to accelerate climate change adaptation and mitigation activities [22].

Furthermore, the creation of ecosystem-focused food production models and the dissemination of digital and climate-friendly agricultural technologies are also significant steps. Additionally, the development of seed varieties tolerant to drought and cold, the conduct of breeding programs for local animal breeds, and the recording and monitoring of agricultural sector practices are essential [23].

Finally, the importance of international cooperation and shared responsibility in protecting against the adverse effects of climate change and ensuring food security is evident, and this issue should be continually on the global agenda through collaboration efforts [24].

CONCLUSION

The effects of climate change on the agricultural sector have been subjected to rigorous examination, and a series of sustainable solutions for ensuring global food security have been put forth. The detrimental impact of global warming, shifts in precipitation patterns and extreme weather events on agricultural productivity has been subjected to rigorous examination. Furthermore, the prospective ramifications of these effects on future food supply and security have been subjected to thorough evaluation.

A variety of strategies and policies have been put forth as means of addressing climate change and preparing the agricultural sector for future challenges. The key strategies highlighted include the strengthening of water management policies, the promotion of sustainable agricultural practices, the development of climate-resistant seeds, and the improvement of agricultural technologies. Furthermore, the necessity of international cooperation and shared responsibility has been emphasised, leading to the conclusion that this issue must remain on the global agenda.

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Review Paper / Derleme Makale

The Impact of Technology on Food Waste: Smart Packaging

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ABSTRACT

Food waste, which is constantly increasing and requires urgent intervention at all stages of the food supply chain, is a major problem. Failure to address this issue leads to larger problems such as biodiversity degradation, the climate crisis, and migration. Technological products are seen as a significant opportunity to prevent waste. Therefore, this study aims to explore the impact of technology on food waste, with a specific focus on smart packaging. By reviewing the literature on the subject, the study discusses and explains technological solutions to food waste (such as mobile phone applications, smart devices, waste recycling, and smart packaging), the relationship between packaging and food waste, and the importance of smart packaging in reducing food waste. In conclusion, it has been determined that technology is a crucial element in combating waste, new technologies should be supported, and the smart packaging system, in particular, plays a key role in preventing waste at the retail and consumption levels.

Keywords: Food waste, Smart packaging, Technology

Teknolojinin Gıda İsrafına Etkisi: Akıllı Paketleme

ÖZ

Gıda tedarik zincirinin tüm basamaklarında devamlı artış gösteren ve acil müdahale gerektiren gıda israfı büyük bir sorun olarak karşımıza çıkmaktadır. Bu sorunun çözülememesi biyoçeşitliliğin bozulması, iklim krizi, göç gibi daha büyük problemleri doğurmaktadır. İsrafın önüne geçmede teknolojik ürünler önemli bir fırsat olarak görülmektedir. Bu sebeple çalışmada teknolojinin gıda israfı üzerine etkisi ortaya konularak akıllı ambalaj özelinde değerlendirilmesi amaçlanmaktadır. Konuya ilişkin alan yazın taranarak gıda israfına çözüm olarak sunulan teknolojik ürünler(cep telefonu uygulamaları, akıllı cihazlar, atıkların geri dönüşümü, akıllı paketleme), ambalaj ile gıda israfı ilişkisi ve akıllı ambalajların gıda israfındaki önemi tartışılarak açıklanmıştır. Sonuç olarak; teknolojinin israf ile mücadelede önemli bir unsur olduğu, yeni teknolojilerin desteklenmesi gerektiği ve özellikle akıllı paketleme sisteminin perakende ve tüketim basamaklarında israfın önüne geçmede kilit rol oynadığı tespit edilmiştir.

Anahtar Kelimeler: Gıda israfı, Akıllı paketleme, Teknoloji

INTRODUCTION

The Food and Agriculture Organization (FAO) has stated that an estimated one-third of all food produced for human consumption is wasted [1]. Therefore, food waste has been as an extremely important global problem for societies [2]. While food still has social, economic, and nutritional values at the service sector and household levels, food waste, which refers to the decision to discard or throw away, creates environmental and socio-economic problems [3, 4]. The World Bank states that more than US$1 trillion in food is wasted every year [5]. However, the report prepared by the United Nations Environment Program stated that 783 million people are struggling with hunger. Considering this number, which is approximately 122 million more than 2019 data, it is important to prevent food waste and use resources efficiently [2]. National and international organizations, the private sector, non-governmental organizations, and researchers are trying to ensure the applicability of the solution suggestions by carrying out important studies at this point [3]. As a result of the studies carried out in this direction, 12 percent of the food produced globally in 2022 was wasted in the retail process [2]. As the cause of waste in the retail process; lack of protective packaging, lack of temperature and humidity control, lack of proper display conditions, tendency to deliver perfect products and inadequate inventory management [3]. The reasons for the waste, which is found to be 60 percent at the household level, are identified as incomplete purchasing planning, ignorance about date labels, inappropriate storage conditions, over-prepared and inedible foods, and incorrect preparation techniques [2, 3]. However, it is stated that the highest food waste belongs to the fruit and vegetable group (31.2 percent). This situation is explained by the perishable nature of fruits and vegetables. Meat and other animal products are detected as 13.1 percent, but it is stated that data collection is insufficient. Roots and tubers are the third group in which food waste occurs with 11.9 percent. Cereals and legumes are found to be the group with the lowest food waste [6]. For example, reasons for wasting bread include buying too much bread and not liking stale bread and the fact that the participants do not know how to evaluate bread [48]. According to the FoodWaste Index Report (2024) when we look at the amount per person, it is concluded that almost one-fifth of all food offered to consumers is wasted, with 132 kilograms [2].Food waste occurs at the retail and household levels in high-income countries. Even though high-income countries have advanced technology, food waste occurs due to household consumption behavior. Food waste in low- and middle-income countries generally occurs at post-harvest and processing stages. This is attributed to low-income countries' lack of proper storage facilities and distribution, limited awareness, and lack of technological advances. The lower waste detected at the retail and household levels is explained by financial impossibilities [7].

When the situation in Türkiye is examined, it is seen that 19.1 million tons of food is wasted every year [8]. The largest share of this waste is calculated to belong to the fruit and vegetable group, similar to the global scale [9]. It is determined that 25-40 percent of the grown vegetables and fruits are wasted and it is stated that this is more than four times of Türkiye's total fruit and vegetables exports. However, it is stated that 4.9 million loaves of bread per day and 1.7 billion loaves of bread per year are wasted in Türkiye [10]. In this regard, the most important work carried out to prevent waste in Türkiye, where the concept of waste is culturally avoided, is the “Bread Waste Prevention Campaign”. With this campaign, 1 million 50 thousand loaves of bread per day and 384 million loaves of bread per year were saved from being wasted [11].

Studies continue to determine the causes of food waste both in Türkiye and the world. In this context, it is necessary to focus on practices that will prevent waste in storage and distribution processes, which are seen as one of the important causes of waste [12]. Research indicates that creating technological infrastructure to keep properties such as temperature, humidity, and light constant during the storage process will prevent food waste [13]. However, it is stated that digital applications in technology will play a key role in preventing food waste in the distribution process [14]. It has been stated that technology is effective in product traceability and stock control and also plays an important role in improving the business environment [15]. As a result, it is emphasized that technology is an important element in preventing food waste [16].

TECHNOLOGICAL PRODUCTS AS A SOLUTION TO FOOD WASTE

Food waste emerges as a growing problem that requires intervention at all stages of the food supply chain. Practices such as durability codes and expiration dates used in this regard create an obstacle to waste. With developing technology, it is considered important to make these systems smarter at the consumer level [17]. Technological products that can be used at every stage of the food chain appear as an important opportunity in reducing food waste [18, 19]. These technological products; mobile phone applications that allow customers to order their meals in advance (Blue Apron, Gram evde, Too Good to Go, No Food Waste, Food Cloud, Yo No Desperdicio, etc.), smart devices (smart pan, smart fork, smart scale, smart refrigerator, etc.) aiming to minimize waste during storage and production in individual kitchens used by middle- and high-income families, systems that enable the conversion of food waste into energy, three-dimensional printing devices that can use alternative raw material sources to produce functional products according to individual consumer needs, and smart packaging. [18, 20].

Mobile Phone Applications**:** These are expressed as practices that aim to prevent food waste by providing food exchange, e.g., bringing excess food to those in need individually or corporately (cafes-restaurants) before it is wasted, fighting against hunger, businesses' delivering the products they will throw away at the end of the day to consumers by applying discounts, customers looking for discounts can follow the discounts created to prevent food waste, ensuring the exchange of raw and cooked food, evaluating companies that produce food waste, and applications that aim to prevent food waste by making food donations easier as the main purpose [21].The program FOODDY provides reliable information by scanning food with a phone camera, providing educational food storage to raise awareness of the environmental impact of food[49]. Similarly, the FoodImage mobile app calculates food quantities through uploaded photos so users can see how much food is eaten and wasted daily [50].

Smart Devices: They are defined as devices that exhibit smart behavior with built-in or embedded sensors in household items such as dinner sets, refrigerators, stoves, coffee machines, ovens and sinks. These devices aim to provide information about the expired product, at what temperature the product should be cooked and for how long, to shop knowing the amount of food available, to determine the amount of consumption needed and to provide information about it, to prevent overeating and to prevent waste that will occur due to overconsumption [22]. For example; smart refrigerators are used as a preservation method that can detect the quality and quantity of food inside through mobile applications and thus prevent food from spoiling and reduce waste [52]. This system, which works integrated with artificial intelligence technologies and smart devices, uploads fresh images of foods and enables it to detect their properties such as texture and shape. The information captured with the help of cameras and sensors placed inside the refrigerator is analyzed and an audible notification is provided to the user. In smart refrigerators, the data obtained with Natural Language Processing Technology and the Internet of Things is recorded and later enables measures to be taken to prevent food waste such as preparing a shopping list, ensuring the consumption of perishable food, reducing the amount of over-produced food, improving inventory management and producing according to consumer demand [53, 54].In addition, the programmable smart lid technology developed to prevent mold formation in open foods; It is presented as an important opportunity to extend the shelf life of food and thus prevent food waste [55]. Another smart device, smart pans, provide information about cooking thanks to the communication of the temperature sensor placed on its base with the mobile device and prevent food waste resulting from the consumer's lack of cooking knowledge. Smart devices developed to measure egg freshness, smart forks and smart scales that determine the calories and nutrients the consumer should take and provide information about how much they eat, smart cocktail shakers and coffee machines developed to apply the right recipe, smart jugs that inform the consumer about the spoilage of the milk in them are smart devices used to reduce food waste [22].

Recycling of Waste: Food waste is divided into two categories: edible and non-edible food waste. Edible food waste is defined as unused, damaged products and food that could have been eaten before being thrown away, and occurs for a number of reasons, including over-purchasing, inadequate preparation, inadequate storage and large portion sizes. Non-edible food waste includes parts that are not produced for human consumption but ultimately end up in the trash, as well as waste from food or beverage preparation. Examples of non-edible food waste include meat fat and sinews, eggs, fruit and vegetable peels [51]. It is provided by the discovery of biomass energy resources consisting of non-fossilized plant and animal organic substances. It is classified as solid biomass, liquid biomass (biofuels) and gaseous biomass (biogas). Solid biomass (plant residues, wood, dung, etc.) has been used for purposes such as heating and cooking since ancient times. It has also been observed that liquid and gas biomass resources have been used recently [23]. Organic waste in the kitchens of food and beverage establishments is used as biogas. It is possible to use it for water heating, lighting and natural gas in kitchens, depending on the methane gas level it contains [12]. Another method used in recycling waste is compost production. Compost production is defined as the process of decomposing organic substances into simpler organic and inorganic substances. With the production of compost, a material with soil regulator properties and fertilizer value is obtained. This material benefits the soil and the growing plant [24].

3D Food Printers: It allows personalized meals and digitalized nutrition, taking into account individuals' age, physical/health status (fitness), nutritional status and energy needs. It is stated that it provides energy, time and cost savings, shows high efficiency and is useful in reducing food losses [20].

Smart Packaging: It provides information about pH, temperature, humidity of the environment where the food in the package is located. With smart packaging, activities are carried out to reduce food waste, such as gaining information about the shelf life, safety, quality of food, possible problems and monitoring and detecting these problems [25].

RELATIONSHIP BETWEEN PACKAGING and FOOD WASTE

It is not possible to consume food products where they are produced and in a short time. The fact that food products can be consumed at different times in different regions requires preservation. Food packaging is defined as a food production stage that delivers food to the consumer safely [26]. The main task of packaging is to protect the food against external factors and ensure that it reaches the consumer in a safe, fresh and delicious way for a maximum period of time [27]. Packaging plays an active role in maintaining food quality, food integrity and food safety. It facilitates distribution and storage processes [28]. In relation to changing living conditions and technological developments, there is a need for packaging to have different features in addition to its protection feature. These features are expressed as providing more information about food and preventing more harmful and wasteful food for the environment [29]. Although packaging largely prevents food waste by ensuring the protection of food, it can also be among the causes of food waste due to its design. Failure to use food-grade packaging material, size and shape can lead to food waste [30]. It is important to choose packaging designs that can reduce food waste and to adopt innovations in food packaging [28]. Studies have expressed the necessity of developing new and improved packaging types while maintaining food safety and quality [27]. Developing packaging that provides better protection helps keep unsold products fresh while they reach those in need or are returned. Preparing packaging for its intended purpose is seen as a practice that will prevent waste throughout the supply chain and makes it easier to understand where and why waste occurs. Designing the packaging itself to be recyclable helps prevent environmental problems. Raising consumers' awareness about reading labels is seen as a practice that will prevent the waste of food that is still edible. However, developing packaging that will appeal to smaller households prevents household waste. It is considered important to adopt new packaging materials and technologies such as smart packaging in order to extend the shelf life of food and reduce outdated stocks [31].

SMART PACKAGING

Smart packaging refers to packaging material that can monitor and control various parameters such as humidity, temperature and gas composition that can interact with products [32]. Smart packaging is defined as packaging systems that provide information to the consumer about the safety and quality of food [33]. Smart packaging used in products such as food and medicine includes embedded sensor technologies [32]. Packages with temperature-time indicators and packages with biosensors can be given as examples of smart packaging, which has features such as sensing, monitoring and signaling. Its working principle is related to temperature-time measurement, enzymatic quality changes, microbiological activity measurement and traceability [27, 34]. Temperature time measurement is a technology that provides a visual summary of the cold chain process and refers to devices used to record thermal history and indicate the remaining shelf life of perishable products throughout their storage, distribution and consumption. It is based on the principle of irreversible color change resulting from the cumulative effects of temperature and time [35]. Biosensor packaging provides information about the development status of microorganisms [36]. Biosensors are defined as analytical tools that detect, record and transmit biochemical reactions. These tools consist of a bioreceptor that detects the target sample and a transducer that converts biochemical signals into measurable electrical messages. Bioreceptors consist of organic materials such as antigens, enzymes, nucleic acids and hormones, and systems such as electrochemical, colorimetric and optical, depending on the parameter measured by the transducer. [37]. It is stated that this technology will be developed in the future and different systems designed for various spoilage reactions in foods will be produced. For example, packaging that increases the purchasing intention by emitting a pleasant scent as the consumer approaches the consumer in the aisles can be given [34].

Considering all this, an innovative smart packaging approach that is effective in preventing food spoilage is vital in solving the challenges of sustainable food production and combating food waste [38]. It is stated that smart packaging will provide positive effects in reducing food poisoning, contamination and especially food waste [39]. Similarly, it is stated that people will be warned with smart packaging techniques and thus waste will be reduced [40]. It is emphasized that by knowing the current quality status of the food at the retail stage, foods with a short shelf life will be sold earlier and waste will be avoided [41]. Consumer awareness through smart packaging is considered important in preventing fresh food waste [42]. Studies indicate that the shelf life of food can be extended and food waste can be reduced by incorporating betalains (e.g. betacyanins and betanin) into smart packaging systems [43]. Additionally, it is emphasized that food waste can be prevented and recycling can be achieved by including food waste in the smart packaging design process [38]. Shelf-life length impacts food waste, with longer shelf life leading to less waste. Examples include the trend toward “clean labels” improving product storage conditions, purchasing behavior to minimize food waste, and alternative smart approaches that support effective home inventory management [56].

CONCLUSION

It is stated that the increase in food waste will cause less availability of food products, which will lead to a rapid increase in food production [44]. Food production requires many resources such as water, energy, fertilizer, pesticides, herbicides, land and labor. Considering that a land mass larger than China is needed to grow food products, it is predicted that serious problems such as deforestation, species extinction, climate change and migration will arise [7]. In order to prevent the emergence of these problems, there is a need to produce urgent solutions for food waste.

Such processes as air pollution, water pollution, and pandemic create disruptions in the supply chain. These disruptions result in food insecurity, defined as a situation in which people do not have access to adequate food due to limited resources [45]. The increase in food insecurity drives people to make decisions such as panic buying, stockpiling, and not buying for fear of being infected [46]. This situation increases food waste, especially in the retail process. Smart packaging, defined as a system that facilitates people's decision-making processes, prioritizes food safety, and includes smart improvements such as monitoring, observing, documenting and communicating, emerges as an effective system at this point [7]. The smart packaging system that guarantees the microbiological, chemical and physical suitability of foods for consumption has not yet been adopted commercially. Therefore, it is necessary to develop cost-effective systems that are fast, sensitive, user-friendly, prioritize food safety and quality, and comply with the legislation and meet consumer demands [47]. Smart packaging tools will be one of the fundamental tools in establishing traceability systems for sustainable food safety. By checking the validity of the "Expiration Date", it will be possible to prevent the consumption of products that have not been stored under the right conditions; since the freshness of the products can be determined, food-borne poisonings can be prevented, thus protecting the health of the consumer and preventing economic losses [37].

Ultimately, the future of food packaging lies in smart packaging that can do more than protect and preserve.

It is thought that waste will be prevented at the retail and household levels with the smart packaging system. In this regard, more studies on the subject need to be done. It is thought that it would be beneficial for public and private sector organizations to focus on solving food waste with technological methods.

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Review Paper / Derleme Makale

Evaluation of Climate Change in the Scope of Agriculture and Food

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ABSTRACT

Global climate change is increasingly manifesting its effects day by day, and Turkey is also facing various adverse influences such as temperature fluctuations, excessive rainfall, drought, and storms. Each region within Turkey's borders has its own unique soil structure, contributing to agricultural diversity. Climate change complicates the cultivation of agricultural products, affecting both product quality and yield, and impacts agricultural labor. Furthermore, it can exert pressure on agriculture by causing social and economic issues. An interdisciplinary approach is essential to examine the effects of meteorological events resulting from climate change. Given the direct impact of climate change on agricultural and food security, it is crucial to analyze its root causes in this field. Measures must be taken to monitor indicators, understand the extent of their effects, and provide explanations accordingly. Evaluating the problems caused by meteorological disasters stemming from climate change on agricultural and food production, along with analyzing soil-economic impacts, is vital for developing solution-oriented recommendations. First, studies aimed at identifying the adversities caused by climate change and formulating scenarios to mitigate them should be planned. Subsequently, strategies should be developed to minimize the negative impacts.

Keywords: Climate change, Agriculture, Food

Tarım ve Gıda Kapsamında İklim Değişikliğinin Değerlendirilmesi

ÖZ

Küresel iklim değişikliği, her geçen gün etkilerini daha fazla hissettirmekte ve Türkiye de sıcaklık dalgalanmaları, aşırı yağışlar, kuraklık ve fırtınalar gibi çeşitli olumsuz etkilerle karşı karşıya kalmaktadır. Türkiye sınırları içindeki her bölgenin kendine özgü toprak yapısı, tarımsal çeşitliliğe katkıda bulunmaktadır. İklim değişikliği, tarımsal ürünlerin yetiştirilmesini karmaşık hale getirerek hem ürün kalitesini hem de verimi etkilemekte ve tarımsal iş gücünü de etkilemektedir. Ayrıca, sosyal ve ekonomik sorunlara yol açarak tarım üzerinde baskı oluşturabilir. İklim değişikliği kaynaklı meteorolojik olayların etkilerini incelemek için disiplinler arası bir yaklaşım gereklidir. İklim değişikliğinin tarımsal ve gıda güvenliği üzerindeki doğrudan etkisi göz önüne alındığında, bu alandaki sorunun kök nedenlerini analiz etmek hayati önem taşımaktadır. Göstergelerin izlenmesi, etkilerinin boyutunun anlaşılması ve buna göre açıklamalar sağlanması için önlemler alınmalıdır. İklim değişikliğinden kaynaklanan meteorolojik felaketlerin tarımsal ve gıda üretimi üzerindeki sorunlarını değerlendirmek ve toprak-ekonomik etkileri analiz etmek, çözüm odaklı önerilerin geliştirilmesi için hayati öneme sahiptir. Öncelikle, iklim değişikliğinin neden olduğu olumsuzlukları belirlemeye yönelik çalışmalar planlanmalı ve bunları hafifletmek için senaryolar oluşturulmalıdır. Ardından, olumsuz etkileri en aza indirmek için stratejiler geliştirilmelidir.

Anahtar Kelimeler: İklim değişikliği, Tarım, Gıda

INTRODUCTION

Climate change is a phenomenon addressed within the context of chronic rather than acute events. Its impacts are observed across all aspects of life due to its potential to cause emergencies and disasters. Among the chronic problem areas that directly affect the agriculture sector are pollution, global warming, excessive population growth, depletion of natural resources, waste, climate change, loss of biodiversity, deforestation, acid rain, water pollution, and harms caused by genetically modified foods [1]. According to the Global Risk Report published by the World Economic Forum in 2023, natural disasters and extreme weather events rank second among short-term risks, while among long-term risks, they rank third, following biological diversity loss and ecosystem disruption, respectively [2]. In this context, climate change can be considered a chronic issue, while the emergency and disaster events it generates can be seen as acute problems [1, 13].

Seasonal dynamics required for agricultural production, climatic conditions, product quality, and production quantity are crucial in agricultural production. Vulnerability to climate change is defined as the physical geography-related ecological or socio-economic impact of climate change stress and pressure on a community or system [3]. Changes in temperature, precipitation type and amount, drought, storms, and tornado events due to climate change deeply affect agricultural products, producers, actors involved in the delivery of these products to final markets, and exporting companies. Economic losses due to drought, floods, storms, and related events in 2022 have increased compared to the 2002-2021 average [4]. Meteorological, climatological, and hydrological disasters related to weather, climate, and water are generally categorized under the umbrella term of hydrometeorological disasters in studies [5-7].

CLIMATE CHANGE PROBLEM AREAS

The World Meteorological Organization defines disasters occurring due to weather, climate, and water as hydrometeorological disasters [8]. These disasters include rainfall, severe local storms, tropical storms, storm surges, severe winter conditions, hail, and frost. Forest fires, agricultural pests, drought, lake and sea level rises, avalanches, and floods are natural disasters closely related to weather conditions. All natural disasters directly or indirectly associated with meteorological conditions are known as meteorological disasters or meteorology-related natural disasters. Floods and droughts can also be referred to as hydrological or hydrometeorological disasters (Table 1) [9-11].

Due to climate change, there has been an increase in the frequency and intensity of such disasters. Data from the General Directorate of Meteorology indicate that average humidity in Turkey has decreased compared to the 1970s, with a tendency for evaporation to also decrease. Turkey is generally facing a climate characterized by higher temperatures, less rainfall, and higher evaporation rates. Projections developed by the General Directorate of Meteorology for the period 2016-2099 involve three different global models. For instance, according to the first scenario, it is expected that Turkey's annual average temperatures will increase by 1.5 to 2.6°C during the period 2016-2099. Although a general decrease in rainfall is expected, there is no continuous trend of increase or decrease in precipitation, but rather an increase in precipitation irregularities is anticipated. Similarly, during the period 2016-2099, it is expected that Turkey's annual total precipitation anomaly will decrease by an average of 3% to 6%; the average change in precipitation anomaly is projected to be between 1% and 6% in the first half of the century and between 5% and 6% in the second half [13].

By predicting sudden-onset natural disasters such as floods, flash floods, and storms, as well as slow-onset disasters like drought and deforestation beforehand, effective disaster management practices can be implemented to prevent and mitigate damage. This would enable the implementation of activities to reduce the impacts on affected sectors, minimize loss of life and property, and reduce the vulnerability of agricultural products, producers, and the economy as a whole, thus enhancing resilience from humanitarian, economic, and social perspectives. In Europe, a project aimed at investigating the effects of extreme weather events, reducing vulnerability, and developing risk communication strategies has been conducted to disseminate risk reduction, prevention, and cooperation efforts [14]. Analyzing the effects of climate change specifically on fig production, a strategic agricultural product with significant production and export share in the Aegean region, from the perspectives of producers, agricultural workers, and exporting companies constitutes the unique value of the project.

When considering the insufficiency of rainfall as a limiting factor for agricultural production, the importance of necessary policies and strategies to increase sustainable food production and water resources becomes evident. Striking indicators and findings mentioned in the Climate Change and Sustainability in Agriculture Report of the Federation of Food and Beverage Associations of Turkey [15]. point to the need for scientific research in this area. The report particularly highlights expected significant decreases in rainfall amounts in the Aegean and Mediterranean coasts, as well as in the Southeastern and Eastern regions of Turkey, leading to rainfall shortages, reduced frequency of frost events, milder winters, but hotter, drier, and shorter-duration summer seasons.

Table 1. Potential effects of hydrometeorological disasters [12]

Hydrometeorological Hazards/Disasters	Potential Effects
Hail	Damage to all field crops, property damage, injuries to humans and animals, transportation problems
Strong Winds and Storms	Property damage, transportation issues, crop damage, forest damage, tree damage, indirect impact on human and animal safety, increased existing security vulnerabilities (forest and other fires, environmental disasters, disruption of rescue operations)
Drought	Significant losses in agricultural production, water supply issues, river transportation, problems in operation of hydroelectric power plants
Spring and Autumn Frosts	Damage to fruits, vegetables, and other agricultural products
Flooding and Floods	Dangers for human and animal habitats, loss and property damage in all weather-related sectors
Fires	Forest damage, endangerment of human and animal lives, significant threat to environment, industry, and other vegetation
Extreme Cold	Endangerment of human and animal lives, thermal and electricity supply issues, road and river traffic issues, forestry damages, agricultural losses, and damages in other economic sectors dependent on weather conditions
Extreme Heat	Endangerment of human and animal lives, problems in electricity supply, traffic issues, favorable conditions for forest and other fires
Heavy and Extreme Rainfall	Flooding and sudden flash floods, risk of mudslides and landslides, disruption of planned agricultural activities, endangerment of human and animal lives, property damage
Prolonged Rainfall	Flooding, problems in all agricultural production activities, traffic issues, risk of landslides and mudslides
Freezing Rain and Ice	Traffic issues (possible traffic blockages), problems in electricity supply - possible major damages in electricity transmission systems, pedestrian injuries
Snow	Traffic and other communication problems, issues in electricity supply
Wet Snow	Traffic issues, issues in electricity supply - possible major damages in electricity transmission systems
Snowstorm	Increased traffic issues and partially or completely hindered rescue operations
Thunderstorms (Thunder and Lightning)	Risk of severe winds and sudden flash floods, along with the risk of thunderstorms, problems in operation for all electrical devices, risk of fire outbreak, telecommunication issues
Fog and Low Clouds	Increased traffic issues and partially or completely hindered rescue operations
Deviation from Normal Climatological and Weather Patterns	Interruption of normal activities in water and food supply, thermal and electricity energy supply, possible adverse effects on tourism and commerce

According to the aforementioned report, given the socio-economic importance of the agriculture and food sectors, it is essential to evaluate the impact of future climate change on crop productivity and food security. Since agriculture and food are expected to be the sectors most affected by climate change in the future, it is important for preventive measures in agricultural production not only to ensure food security but also to avoid adverse effects on the Turkish economy. Recent unprecedented tornado and storm events in the Aegean and Mediterranean regions have resulted in not only loss of life but also significant economic losses [3].

The Turkish Climate Change Strategy [16] outlines short-term objectives such as promoting conscious fertilizer use; limiting emissions by using modern techniques in irrigation, soil tillage, and agricultural spraying; supporting and promoting organic farming and the production of drought-resistant plant species with certified seeds; identifying the current situation regarding deforestation and degradation of forest areas, and developing a strategy to solve these problems; conducting scientific research on the effects of climate change on forest ecosystems and developing adaptation strategies based on these studies; and producing policies based on these researches.

Medium-term goals include implementing crisis management based on agricultural drought prediction; identifying drought-resistant tree species, especially in drought-prone and semi-arid areas, and afforestation with these species; and applying fertilization based on soil analysis requirements to reduce the adverse effects of climate change on soil and water resources and ensure conscious chemical fertilizer use." Long-term strategies emphasize "the planning and implementation of forest areas and forestry activities according to upper watershed management principles, which are of great importance for the conservation and sustainability of water resources.

In the short-term goals of Climate Change Adaptation strategies, efforts will be made to strengthen capacity to combat animal diseases and plant pests arising from climate change. Effective measures against potential pests such as insects, fungi, and others that may increase in forest areas due to rising temperatures will be considered. Scientific studies on the sustainable use of natural resources will continue, considering the interaction between climate change and sectors. Efforts will be made to raise awareness, educate, and support scientific and social initiatives for climate change adaptation among local authorities, professionals, and the public. Policy and strategy development, international communication, and information transfer will also be pursued. Legislation related to disaster and risk effects will be reviewed with a focus on resettlement based on risk reduction. Educational activities will be conducted to increase societal awareness and participation regarding the potential disaster and risk effects of climate change. Local meetings, broadcasts, television programs, and similar events will be planned accordingly.

Similarly, a strategy exists for the detection of potential natural disasters such as floods, avalanches, and landslides, with efforts initiated using early warning systems to minimize their effects. This strategy aligns with the core focus of the project, aiming to shed light on the current situation of fig production and employment in the field. An analysis of the susceptibility to climate change will be conducted nationwide, evaluating its impacts on health and food security. Efforts will be made to accelerate the development of plant and animal species resistant to heat, drought, diseases, and pests.

In the long term, the goals of minimizing the impact of climate change-induced heatwaves, extreme cold, floods, storms, and droughts on public health will be monitored. Efforts will be made to ensure that the public health is minimally affected by these weather events. These objectives highlight the need for academic and scientific research to support efforts related to climate change and agricultural sustainability.

EFFECT of CLIMATE CHANGE on FOOD PRODUCTION

Agricultural food production is highly dependent on temperature and rainfall, making crops vulnerable to climate change. In a seminal assessment of the potential impacts of climate change on agriculture by Nelson (2009), it was concluded that while some regions may experience yield increases in certain crops, rising temperatures are expected to decrease crop yields and promote weeds and pests. Changes in rainfall patterns are likely to increase the likelihood of crop failures in the short term and lead to a decrease in production in the long term. Findings suggest that populations in developing countries, particularly those without food security and vulnerable to climate change, are likely to be disproportionately affected. The results of the analysis undeniably indicate that despite productivity gains in some regions, agriculture and human well-being will be adversely affected by climate change.

The impacts of climate change on agriculture and human welfare can be categorized into biological effects on crop yields, effects on prices, production, and consumption, and effects on per capita energy consumption and child malnutrition. With climate change expected to adversely affect global food production, achieving sustainable food production in the future will become even more challenging, making climate change an increasingly critical issue [17].

CLIMATE CHANGE and FOOD SECURITY

There is a widespread consensus in the literature that anthropogenic greenhouse gas (GHG) emissions contribute to climate change. This will have a range of effects, including changes in food production and supply [18]. In the literature, much focus has been placed on the impacts of climate change on food security in the developing world. Findings suggest that climate change will exacerbate existing and anticipated food insecurity and malnutrition issues [19]. For example, by the end of this century, average summer temperatures are projected to exceed historical maximum values in tropical and subtropical regions, potentially affecting up to 50% of the population living in these regions and leading to serious consequences for food production [20].

Climate change is likely to have implications for food security in developed countries as well. Anthropogenic GHG emissions and natural climate forcings [21]. lead to climate change and specific environmental impacts affecting agriculture and food processing. The agricultural food industry will be affected by efforts to adapt to changing climates and to reduce GHG emissions associated with the food chain [22]. All these changes will result in alterations in the types of foods consumed, their nutritional content, and their safety.

FOOD PRICES and AVAILABILITY

Several studies have examined the potential impact of climate change on world food prices, with a particular focus on grains. [23] found that there was little change or a slight decrease in grain prices with a global temperature increase of up to 3°C, but prices began to rise as production declined. However, many assessments do not consider the likely increase in frequency of extreme weather events under climate change. Considering these assessments, Easterling. [23] (2007) concluded that crop prices are likely higher than what published assessments suggest.

As an example of the impact of current climate variability, extreme weather conditions in many parts of the world, particularly in the Murray-Darling Basin in Australia in 2006, led to a decrease in global cereal production. These declines in productivity can be partially attributed to the subsequent increase in global food prices [24]. Another example is the 25% decrease in French fruit harvests following the 2003 European heatwave [20].

CHANGING PRODUCTION METHODS

With climate change, food will be produced in different climatic conditions within changing ecosystems. Efforts through initiatives in the food industry can alter conditions to mitigate climate change. Production, processing, transportation, storage, preparation, purchase, and consumption activities in the food sector account for 15-30% of global GHG emissions. Most greenhouse gas emissions from the food sector occur within agriculture (45%), food production (12%), and transportation (12%) [25]

Climate change can alter the number of pests and diseases with seasonal patterns that may affect pesticide use, including herbicides and fungicides. Examples of potential mechanisms that may increase under climate change include volatile and dust-associated contamination of air inputs, flooding, changing environments, and increased bioavailability of heavy metals due to soil characteristics [26]. Results may vary between products and geographical locations. For instance, Chen and McCarl [27] predicted an overall increase in pesticide use in the United States due to climate change. Climate change can also affect the transportation of pathogens and chemicals into food.

Mycotoxins, a significant public health issue, result from complex interactions between fungi and crops and are influenced by air and soil. A recent study showed that as temperature increases associated with climate change approach optimal levels for aflatoxin production, one of the most important mycotoxins for public health, mycotoxin problems have increased in some temperate regions of Europe and the United States. However, in other countries like Australia, temperatures may rise to levels sufficient to reduce fungal growth and mycotoxin production [28].

Climate change is expected to lead to changes in food production areas, indicating that future foods will be sourced from different regions of the world [23].

The source of food, different varieties grown, changing soil structure and cultivation conditions, varying harvesting methods, processing, and storage methods can affect the micro and macronutrient composition. An example of how geographical sources can affect food composition is selenium, which can be protective against various cancer types. The UK population obtains most of its selenium from grains. Between 1970 and 2000, there was a 50% decrease in selenium intake in the UK diet coinciding with the transition from grain imports from Canada to domestic production on selenium-poor soils in the UK [29]. There is evidence that daily selenium intake in the UK is below recommended levels [30].

In the European Union and many other countries (such as the UK), permissible levels of various contaminants (microbial, chemical, and radiation) in food are determined internationally through the FAO/WHO (2006) Codex Alimentarius Commission. Therefore, if levels of food contaminants exceed the established levels, such foods will not be allowed to enter the human food chain. Some food retailers ensure that their suppliers adhere to values below legal limits [31].

Processes allowed in agriculture and food businesses are tightly controlled to ensure food safety. Examples include EU Food Hygiene Regulations (European Parliament and Council of the European Union) and EU Plant Protection Product Regulations (European Parliament and Council of the European Union). Standards and regulations will help prevent food and safety issues arising from climate change.

IMPACT of CLIMATE CHANGE on AGRICULTURE in TÜRKİYE

The agricultural sector can be vulnerable, especially to natural events and disasters. This vulnerability stems from the fact that productivity in the agricultural sector largely depends on climatic conditions. Climate-related weathser events can adversely affect agricultural production and incomes, leading to various risks in the short and long term [32]. Climate change affects crop production, markets, food prices, and supply chain infrastructure. It also has significant implications for global food security [33]. Predicting global and regional climate changes, reducing their potential impacts, and adapting to them are crucial. Consequently, climate change has become an increasingly important research topic among scientists. Extreme weather events have negative effects on crop and livestock production, forest ecosystems, rural production, and fishing. This leads to losses in productivity and employment [34]. For instance, Al-Amin and Ahmed [35] examined climate change adaptation and cost benefits using an experimental, dynamic, and adaptable general equilibrium model for Malaysia. They found that due to the effects of climate change, the food sustainability gap increased over time. Dawson [36]. predicted that by 2050, if no adaptation or agricultural innovation is made based solely on projected changes in population and agricultural land use, 31% of the global population would be at risk of inadequate nutrition. Considering the effects of climate change, it is expected that 21% of the global population will be at risk of inadequate nutrition. Addressing future food security gaps requires an integrated food system approach rather than relying solely on technological advancements in agriculture [37].

The potential impacts of climate change on agriculture in Turkey have been a research topic, particularly since the 2000s. Studies focusing on the effects of climate change on fig cultivation are limited, with research on climate change and agriculture predominantly concentrated on grains. Kanber [38] investigated the effects of climate change on agriculture and predicted a significant decrease in rainfall. They also indicated that snowfall amounts and melting times would change, affecting the planting times and areas for certain crops (such as wheat) in Turkey. Dumrul and Kılıçarslan [39] empirically evaluated the effects of climate change on the Turkish agricultural sector for the period 1961-2013, finding that increasing temperatures and decreasing rainfall negatively affected agricultural gross domestic product. It has been observed that severe wind and tornado events in Turkey have had adverse effects on agricultural production, causing damage to crops, greenhouses, and agricultural processing facilities, leading to economic losses [40]. For example, on January 24, 2019, a tornado originating from the sea caused significant damage to greenhouse areas in Kumluca, Antalya. The tornado, with a width of 50-100 meters and a length of 5 km, tore and carried away PVC greenhouse films, causing substantial damage. Additionally, it bent and partially dislodged the metal frames of many greenhouses, rendering them unusable. Glass greenhouses experienced broken glass panels, scattering glass shards across agricultural fields [41].

Increasing temperatures contribute to the exacerbation of water crises in agriculture and exert pressure on limited water resources. Dry and hot weather conditions lead to decreased crop yields, fallow arable land, and increased costs of water use. The cost of water creates an impact that will lead to cost inflation in agricultural crops and the food supply chain. In their study, Tellİ [42] highlighted the combat against climate change and its socio-economic impacts as an analytical initiative aimed at integrating sustainable development principles into both macroeconomic and sectoral levels of national development planning and environmental policy objectives. However, such studies predominantly focus on the economic effects of environmental policies and environmental taxes across employment, labor force, producers, and exporting firms.

CONCLUSION

The inability to meet the world's food production needs due to factors such as declining agricultural areas, animals at risk, dwindling clean water sources, increasing pesticide use, rising production costs, and a growing global population is expected to become a major problem in the future. Food systems are highly sensitive to the adverse effects of climate change. Solutions aimed at promoting agroforestry, reducing waste, and adopting sustainable eating habits within food systems do not require high investment or technological processes compared to other industries. Additionally, implementing improvement processes will not only reduce emissions but also foster development in areas such as food security and biological diversity.

The impact of climate change on food production is geologically and temporally variable and highly complex. The effects of climate change on food production can be evaluated in two ways: direct and indirect effects. Agricultural and ecological impacts are considered indirect effects within the scope of direct effects, while economic growth and income distribution are considered indirect effects. Access to a sufficient level of safe food is a right that everyone should have to meet their daily needs and maintain a healthy life. Solutions and plans addressing the adverse effects of temperature changes and climate extremes on food production, the effects on freshwater resources, and changes in atmospheric gas ratios should be provided. It is known that adverse conditions arising from climate change will affect agricultural productivity, but it is possible to mitigate the resulting negative consequences in various ways. It is considered that raising awareness among producers about new efficient technologies and directing them towards sustainable agricultural production are strong adaptive strategies. In short, failure to take urgent action will negatively affect many people, changing climate conditions will harm crops and animals, and destroy harvests. This process will lead to the emergence of a food crisis in addition to the climate crisis.

Increased temperatures due to climate change, changing climate seasons, extreme weather events, and disasters necessitate increased awareness-raising activities in agricultural production and animal husbandry related to food production, integration of insurance systems to prevent income losses, and emphasis on activities to prevent indiscriminate water use.

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Review Paper / Derleme Makale

Trends in Sustainability and Innovative Food Packaging Materials: An Overview

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ABSTRACT

Globally, 1.3 billion tons of food are wasted or lost every year. This loss is valued at US $2.6 trillion and accounts for 8-10% of greenhouse gas emissions (GHG). Food waste is a significant source of greenhouse gas emissions and results in a waste of natural resources. Therefore, reducing food waste can help diminish GHG emissions, improve food security, and promote healthy food systems. Packaging plays an important role in protecting food, enhancing quality and safety, and reducing food losses. Innovative and sustainable packaging strategies are necessary to decrease waste accumulation, particularly of plastics, safeguard food quality and safety, and reduce food losses and waste. Sustainable packaging aims to enhance the effectiveness of design and the use of environmentally friendly materials. This review provides an overview of the sustainable status of common packaging materials such as plastic, glass, metal, and paper/cardboard based on the circular economy, which includes recycling, reuse, composting, and bio-based packaging. The study examines new developments in food packaging materials in response to the growing demand for environmentally sustainable alternatives. Several applications from food companies and sustainable studies are discussed regarding continuous availability without impacting the environment. Ongoing research and technological advancements, such as material reduction, the development of innovative new materials like bio-plastics, and improvements in recycling, will contribute to increasing the acceptance of sustainable packaging. Definitions, requirements, limitations, legislation, and applications of sustainable packaging are explored. Sustainable packaging can stimulate economic growth and offer new opportunities for companies, notably by helping the environment and reducing the carbon footprint. However, the cost of sustainable packaging can still be challenging for small businesses. Determining whether consumers are willing to pay more for sustainable packaging is also crucial in this transition.

Keywords: Sustainability, Sustainable packaging, Eco-friendly materials, Biopolymer, Less-waste

Sürdürülebilirlik ve Yenilikçi Gıda Ambalajlama Malzemelerindeki Eğilimler: Genel Bakış

ÖZ

Dünya çapında her yıl 1.3 milyon ton gıda israf ediliyor veya kayboluyor. Bu, 2.6 trilyon ABD doları değerinde ve sera gazı emisyonlarının %8-10'unu oluşturuyor. Gıda israfı, sera gazı emisyonlarının ve doğal kaynakların israfının başlıca kaynaklarından biridir. Bu nedenle, gıda israfını azaltmak, sera gazı emisyonlarını azaltmaya, gıda güvenliğini artırmaya ve sağlıklı gıda sistemlerini teşvik etmeye yardımcı olabilir. Ambalaj, gıdayı korumada, kalite/güvenliği iyileştirmede ve gıda kayıplarını azaltmada önemli bir rol oynar. Atık birikimini, özellikle plastikleri azaltmak, gıda kalitesini/güvenliğini korumak ve gıda kayıplarını ve israfını azaltmak için yenilikçi ve sürdürülebilir ambalaj stratejileri gereklidir. Sürdürülebilir ambalaj, tasarımın etkinliğini ve çevre dostu malzemelerin kullanımını artırmayı amaçlamaktadır. Bu inceleme, geri dönüşüm, yeniden kullanım, kompostlama ve biyolojik bazlı ambalajı içeren dairesel ekonomiye dayalı olarak plastik, cam, metal ve kağıt/karton gibi yaygın ambalaj malzemelerinin sürdürülebilir durumuna genel bir bakış sunmaktadır. Çalışma, çevreye uygun ikamelere olan artan ihtiyaca yanıt olarak gıda ambalaj malzemelerinde yeni gelişmeleri incelemektedir. Gıda şirketlerinin çeşitli uygulamaları ve sürdürülebilir çalışmalar, çevreyi etkilemeden sürekli kullanılabilirlik konusunda tartışılmıştır. Malzeme azaltma, biyo-plastikler gibi yenilikçi yeni malzemeler ve geri dönüşümdeki iyileştirmeler gibi devam eden araştırmalar ve teknolojik gelişmeler, sürdürülebilir ambalajın kabulünü artırmaya katkıda bulunacaktır. Sürdürülebilir ambalajın tanımları, gereklilikleri, sınırlamaları, mevzuatları ve uygulamaları tartışılmaktadır. Sürdürülebilir ambalaj, ekonomik büyümeyi teşvik edebilir ve şirketlere yeni fırsatlar sunabilir, en azından çevreye yardımcı olarak ve karbon ayak izini azaltarak. Ancak, sürdürülebilir ambalajın maliyeti küçük işletmeler için hala bir zorluk olabilir. Tüketicilerin sürdürülebilir ambalaj için daha fazla ödeme yapmaya istekli olup olmadıklarını belirlemek de bu geçişte önemlidir.

Anahtar Kelimeler: Sürdürülebilirlik, Sürdürülebilir ambalaj, Çevre dostu malzemeler, Biyopolimer, Az atık

INTRODUCTION

Over 25% of the annual global food supply is lost or wasted. According to the Food and Agriculture Organization (FAO) and the United Nations Environment Program (UNEP), the annual global volume of wasted or lost food amounts to 1.3 billion tones, valued at US$2.6 trillion, and contributes to 8-10% of greenhouse gas (GHG) emissions. Food wastage serves as a significant contributor to greenhouse gas (GHG) emissions and the depletion of natural resources. Therefore, mitigating food waste can effectively reduce global GHG emissions, enhance food security, and foster sustainable food systems [1, 2].

In addition to serving as a means of product protection and preservation, extending shelf life, providing information, ensuring traceability, and enhancing the convenience of food products, packaging plays a key role in facilitating the monitoring of food safety and quality throughout the entire supply chain - from production to consumption and reuse/recycling. Appropriate packaging stands as a pivotal element in enhancing food preservation, quality, safety and in the minimizing of food waste at almost every stage of the food chain [3]. As per the U.S. Environmental Protection Agency (EPA), food and its corresponding packaging materials contribute to almost half of the total municipal solid waste generated. Commonly used food packaging materials include plastic, glass, metal, paper, corrugated fiberboard and laminates/extrusions of paper and plastics. Polymeric materials emerge as the predominant choice among packaging options for food, owing to their lightness, cost-effectiveness, formability, flexibility, durability and versatility in terms of color and transparency. In the prevailing plastic-centric economy, packaging materials mostly rely on petroleum-based polymer sources. Despite witnessing a twofold increase in global plastic production over the past two decades - escalating from 234 million tons in 2000 to 460 million tons in 2021 - only 9% of the plastic waste generated in 2021 underwent recycling processes [4].

The disposal of significant quantities of packaging waste into landfills following the single-use utilization of food packaging exacerbates environmental problems by contributing to issues such as leaching into aquatic ecosystems and the proliferation of microplastics. With their omnipresence microplastics, tiny particles less than 5 millimeters in size, have become a matter of growing concern for the environment and human health. Despite a temporary reduction in plastic consumption (2.2%) amid the COVID-19 pandemic, the surge in littering, the heightened reliance on takeaway packaging, and the increased single-use of medical plastic items like masks have resulted in a waste generation world [5, 6].

The environmental repercussions associated with packaging materials, whether during their manufacturing or post-consumption disposal, stand as a significant focal point of concern [7]. Frequently, these materials are discarded following a brief period of utility, thereby contributing to environmental concerns as described previously. In order to minimize the environmental footprint of a packaging, both the intrinsic and the extrinsic attributes of the packaging can be changed. In this respect, packaging sustainability is expressed as the endeavor to minimize the package's footprint through altering the package more environmentally friendly materials [8].

DIMENSIONS of SUSTAINABILITY

The fundamental dimensions of sustainability are economic, environmental and social considerations as user-friendliness [9, 10]. There is a growing attention on the environmental aspect while the economic and social considerations are often ignored. It is evident that the adoption of sustainable packaging practices, characterized by the utilization of eco-friendly materials and conscientious design approaches, is imperative to mitigate any adverse environmental impacts of packaging while preserving food quality and ensuring food safety [11]. Packaging plays an essential role in encouraging sustainable patterns of food consumption, seeking to curtail waste generation and mitigate environmental harm through the adoption of sustainable packaging solutions. Strategies aimed at minimizing waste within the context of sustainable packaging include: (a) Reduction and reusability principles; (b) Substitution of traditional materials with recyclable or compostable alternatives; and (c) Promotion of recycling practices to facilitate the creation of recyclable packaging materials derived from reusable sources, thus creating a sustainable approach characterized by reduced packaging waste and enhanced resource efficiency [12].

The dynamic and rapid evolution of consumption patterns has facilitated the expansion and heightened significance of the packaging sector. Consequently, packaging manufacturers are compelled to proactively engage in initiatives aimed at safeguarding the future and fostering sustainable production practices through the development of eco-conscious products that align with evolving consumer behaviors. Circular packaging solutions are anchored on the principles of "reduce-reuse-recycle", encompassing strategies such as reducing the prevalence of single-use plastic, advocating for material reuse and recycling, while enhancing the economic viability and quality of recycled plastic materials. Industry stakeholders are increasingly prioritizing the adoption of circular economy principles as the foundation for sustainable packaging practices, where materials are utilized efficiently, natural elements are incorporated into designs, and recyclability is emphasized to promote a more environmentally conscious approach [13].

The integration of environmentally sustainable materials in packaging aims to ensure that no detrimental impacts occur to product quality. A critical consideration is that packaging materials need to be manufactured from substances capable of upholding their primary function of safeguarding products, lightweight to reduce transportation costs, can be recycled or undergo biodegradation without posing harm to the environment. The adoption of sustainable packaging practices prioritizes the preservation of human health and environmental integrity through the selection of packaging materials. Within the framework of sustainability, efforts are being directed towards reducing both the volume of packaging materials used and the associated energy consumption, in alignment with the overarching objectives of resource efficiency and environmental protection [13].

SUSTAINABLE PACKAGING

Sustainable packaging is characterized by the following attributes: It should exhibit functionality, be safe to use, and promote the safe and healthfulness of products during its entire life cycle. It should aim to minimize packaging waste generation. It should be manufactured by adhering to good, manufacturing practices and when possible, by incorporating cutting-edge technologies. It should prioritize the optimization of materials and energy through innovative design methodologies. It should have lower GHG emissions and overall environmental impact. Preference should be given to the adoption of innovative and sustainable packaging materials that align with eco-friendly principles [7]. These packaging systems must be economically feasible and provide the desired consumer benefits if they are to compete with traditional packaging.

Using sustainable materials is one of the most reasonable ways to minimize packaging's impact on the environment. Traditional packaging materials are mostly produced using resources such as petroleum. Renewable resources such as wood, bamboo, sugar cane and even cork can be used to make sustainable packaging materials. Traditional materials require substantial energy in their production, which can increase greenhouse gas emissions [14]. Sustainable packaging can reduce our dependence on non-renewable resources [7]. Sustainable packaging involves not only environmentally friendly materials but also tailoring the packaging system design for maximum effectiveness. Lightweight and compact packaging helps reduce transportation costs while also reducing the waste. Efficient packaging can significantly impact a company's ability to reduce its GHG footprint, operating and transportation costs. This is especially important as e-commerce expands. The sustainable packaging arena is constantly changing and may include everything from [10]. Active packaging brings huge advances in the extension of product shelf-life and food degradation and losses reduction [15]. These developments not only help the environment, but also stimulate economic growth and offer companies new opportunities to stand out in the marketplace. Sustainable food packaging reduces the negative burden on packaging resources and packaging waste management, as well as reducing food losses and waste [10, 13].

Innovative packaging solutions to protect and enhance the shelf life of food needs the dynamism of research to create well-designed packaging that adapts to a specific foods requirement and has the needed functional features. Sustainable packaging materials must reduce energy usage in their life cycle production and have a reduced ecological footprint [16]. Innovative sustainable packaging aims to reduce the carbon footprint of packaging during life cycle, reduce food waste and maintain food quality [17]. It must also help control food safety concerns such as foodborne diseases and migration of chemical contamination from packaging to food [15].

SUSTAINABLE PACKAGING MATERIALS

There are a variety of food packaging materials that can be used safely, effectively, and sustainably. When choosing food packaging materials, several factors should be take into account: properties of packaging material, type of food to be packaged, food/package interactions, desired product life cycle, environmental conditions during handling, product end use, eventual package disposal and costs [18].

Paper, corrugated fiberboard

Paper and corrugated fiberboard packaging is mainly made from plant sources and break down naturally over time [19]. Paper packaging has advantages such as ease of use, low cost, lightness, utility and has a substrate conducive to providing information to consumers [19]. Paper has the highest recycling rate (4-7 times) among all packaging materials [20] and biodegradable material [19]. This feature makes it an environmentally friendly choice that reduces waste accumulation in landfills and minimizes the carbon footprint associated with disposal. However, ink and coating residues can negatively affect recyclability due to contain residual chemicals from the printing process [21]. This could create regulatory concerns if the recycled paper is to be in contact with food. Paper-based packaging is not a water or oxygen barrier and can therefore be easily damaged when it comes into contact with water or moisture [22]. Paper and corrugated fiberboard have advantages over plastic, metal and glass as packaging materials in terms of sustainability and cost. Paper based materials can be used in multi-layered and it is used by combining layers (enable sealability) with polyethylene (PE) and other polymers to improve its barrier function. While the combination of paper with other materials makes paper less sustainable, it increases its use [11]. For instance the Tetra Pak™ containers utilize several layers of material; paper increases its durability, PE improves its water transmission and acts as a binding layer, and as the inner seal layer, and the aluminum foil layers increases its oxygen barrier [20, 23].

The most important advantage of paper-based packaging materials is the perception that they benefit all stakeholders and the environment as a sustainable material. Trees or cellulose-derived plants are renewable resources through planned production and management. However, the manufacturing process of paper can lead to deforestation, water pollution, and chemical use, as well as generate substantial amounts of waste. Substantial energy and water are used in its initial production and can result in large amounts of waste water. Primary air emissions include carbon monoxide, sulfur dioxide, nitrogen oxides, volatile organic compounds and particulates [20].

Pulp fiber may be bleached using chemicals to improve the brightness and whiteness of the paper, thus increasing its printability and appearance. Standard bleaching uses chlorine, chlorine dioxide, or hydrogen peroxide and these chemicals can be released into the environment. More sustainable bleaching methods, such as the use of ligninolytic enzymes, are being investigated. Paper alone does not provide sufficient protection for food packaging due to its poor barrier properties, poor thermal adhesion, and durability in the present of moisture. Untreated paper-based materials are sensitive to moisture, oxygen, mineral oils and chemicals. Obtaining necessary barrier properties generally involves laminating materials with suitable barrier coatings (aluminum, ethylene vinyl alcohol-EVOH and polypropylene, others) to give the desired properties (increasing the barrier). Examples of such papers are waxed paper, a paper coated with wax to improve its barrier properties, and glycine paper, a paper produced at high density to provide resistance to oil. The barrier properties of papers are commonly controlled by the application of conventional petroleum-based derivatives such as polyethylene, polyvinyl chloride, polypropylene, polystyrene, waxes and/or fluorine-based derivatives as coatings [24]. The formulations purposely designed for multi-objective barrier properties, containing pullulan, sodium alginate, poly(vinyl alcohol), and minerals, lowered water vapor transmission rate by one order of magnitude [25]. Changes to paper processing methods can also improve its functional properties. Coating materials with various polymers can add needed properties [20]. Coating synthetic polymers onto paper-based materials reduces the biodegradability and recyclability of paper. Different biodegradable biopolymers such as polylactic acid (PLA), polyhydroxy alkanoates (PHA), starch, chitosan, natural rubber latex and polysaccharides can be used as sustainable barrier coatings in paper packaging applications [26]. Impregnating paper with additives during paper processing, such as colorants, optical brighteners, sizing or strengthening agents, is a common solution to improve paper properties for packaging [20].

Molded pulp packaging is a 100% biobased product generally produced from wastepaper and other natural resources that are compostable and biodegradable. Interest in sustainable packaging has led to increased use of molded pulp packaging. Molded pulp packaging can be used for clamshell packages or to protect fruits, vegetables, eggs and electronics during shipping [20]. By choosing paper packaging, businesses not only contribute to a greener future, but can also improve their brand image, meet legal requirements, and provide convenience to their customers. Adopting paper packaging is a step towards creating a more sustainable and environmentally conscious society. Interest in cellulose nanomaterials (CNs), which contain cellulose fragments with at least one dimension in the nanoscale, has increased. Compared to other nanoparticles, CNs are lighter, more environmentally friendly and have cost advantageous. CNs are attracting attention in sustainable packaging, thanks to features such as high strength, transparency, low thermal expansion and barrier properties [20, 27]. Cellulosic fibers have been added to plastic-based composites as fillers or reinforcements for many years, and in recent years the addition of CNs to bioplastics provides thermal stability, Improved chemical stability, and good mechanical and barrier properties while maintaining the transparency of the plastic [20].

The CNs practices are a good example of sustainable packaging. This means coating paper or bioplastics with CNs to improve properties. Adding CNs in thin layers to the paper surface reduces surface roughness. CNs added as coatings to paper and plastic have improved their O_2 and H_2O barrier properties. CN coatings on corrugated fiberboard or paper have not been shown to improve properties [20].

Plastic

Plastics are the most used materials to produce packaging in the food industry; about 320 million tons of plastic are produced annually, and the demand is growing every year [28]. Petroleum-based polymeric materials [polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET)] are widely used as packaging materials. Plastics have many advantages such as ease of shaping, versatility, good barrier properties, lightness, and affordable cost.

Most food products are needed in multilayer packaging materials with different properties. Each layer provides different properties to the multilayer structure including barrier (e.g., metalized film or aluminum foil) to water vapor, oxygen and other gases, adhesion, strength, printability, and compatibility with the food product. However, multilayer packaging is not recyclable because the layers are very difficult to separate [11, 21]. They are commonly used in the food industry due to their natural properties. However, plastic packaging materials have become a major concern due to their potential negative environmental impact [29]. Petroleum-based polymers are not biodegradable and have a recycling rate of less than only 10% (all the plastic ever produced) [30]. However, the recycling rates of some specific plastic (PET and HDPE was around 30%) were more significant [31]. Many chemical additives are also used in the production of plastics to provide flexibility, color and resistance to heat or sunlight. During production greenhouse gas emissions (CO_2, nitrous oxides, hydrofluorocarbons) may be released which could pollute the air, soils, and waters (seas and oceans) if improperly processed or recycled. Some may also be a source of microplastics that concern because of their widespread presence in the environment and the potential physical and toxicological risks they pose to organisms [32]. This is why the European Union (EU) Commission has set a target of reducing plastic waste by 55% by 2025 and that materials are 100% recyclable or reusable by 2030. However, this is difficult as not all plastic is collected for recycling and some types of plastic are easier to recycle than others. While some types of plastics (PET, HDPE, and PP) are more easily recycled than others. Some (PVC, LDPE, PS) are inherently inefficient to recycle, either economically or environmentally (not widely recycled), and thus are often used only once, causing environmental concern [12]. Retaining plastic industries in a circular economy would save the cost, time, energy of manufacturing and encourage innovation from used items while reducing dependence on new plastic manufacturing [33]. Therefore, to overcome these problems, great attention has been paid to environmentally friendly sustainable polymeric materials that will replace these materials and yet meet the needs of consumers [7].

Sustainable polymers are materials derived from renewable, recycled and waste carbon sources and their combinations that can be recycled, biodegraded, or composted at the end of their life. The preferred rational design of sustainable polymers is built around their synthesis from renewable monomers and that have been continuously (re)oriented for more than decade in their lifetime. Creating sustainable polymers from renewable monomers involves the associated production and use of new bio-based polymers that have the same chemical structure as their fossil-based analogues. Examples of these include bio-based polyethylene (bio-PE) and bio-based poly (ethylene terephthalate) (bio-PET) or polylactide (PLA) and poly(ethylene 2,5-furandicarboxylate) (PEF) [34].

Scientific efforts involving the design, synthesis and production of sustainable or green polymers have expanded tremendously over the last two decades. From a commercial standpoint, there are several leading candidates, each with their own sustainability metrics. Sugar is the most used raw material for these. Sugar fermentation produces the Polylactic acid (PLA), polyhydroxyalkanoates, poly (butylene succinate) (via biosuccinic acid), biopolyethylene (via bioethanol), biopolypropylene (via bioethanol), biopolyvinyl chloride (via bioethanol), polyethylene terephthalate (from bioethanol and conventional terephthalic acid) and polypropylene terephthalate (e.g. bio-1,3-propanediol and Sorona from conventional terephthalic acid). Other promising commercial polymers include polycarbonates made from isosorbide (chemically produced from glucose) or from copolymerization of carbon dioxide and epoxides [35]. Currently marketed bio sourced bioplastics (like Bio-PE, PLA, and more) use food sources like corn or sugar cane. Moreover, most of these bio-sourced bio-plastics are not biodegradable or home compostable (bio-PE, bio-PET) or are only suitable for industrial composting (PLA), which contributes to complicated waste management (separate collection of waste) [36].

PLA is a great business success story. One of the most visible is the scalable production process of PLA from corn via fermentation technologies (beverage containers in fast food restaurants). Twenty years ago, PLA was about 15-20 times more expensive than PET, but today PLA is only 15-25% more expensive than PET. However, PLA has some inherent disadvantages, such as a low glass transition temperature (55-60 °C) and reliable degradability, which is limited by stringent industrial composting conditions. The search for the ideal sustainable polymer continues [20, 35]. Researchers have and are focused on improving the mechanical and physical properties of biodegradable bio-based polymers such as proteins, polysaccharides, lipids and plant sources (e.g. cellulose, starch, chitosan, corn zein, whey protein, waxes, collagen, etc.).

In the next decade, sustainable polymer development will advance in various directions. Several strategies are outlined here, with retain significant potential for future optimization:

(1) Synthesizing water-degradable polymers that do not depend on narrow biological conditions for biodegradation, such as those that contain an acetal functional group.
(2) Insertion of specific functional groups into the polymeric main chain through functional group metathesis polymerization.
(3) Utilization of lignin-based aromatics to expand the operating temperature range of green polymers; and
(4) Development of new polymerization chemistry to use abundant, cheap, and renewable C1 feedstocks.

Consumer demand for functional and inexpensive green polymers is increasing. As global awareness and regulatory pressures on environmental sustainability intensify, bioplastics are increasingly seen as a viable solution to reduce dependence on fossil-based plastics and thus reduce potential pollution from plastics.

Bioplastics are generally divided into two main types based on their properties and source materials: bio-based (renewable sources such as corn starch, sugar cane or cellulose) and biodegradable (can be broken down into natural substances under certain conditions) plastics. One promising polymer is polyethylene furanoate, a 100% bio-based alternative to the petroleum-based PET used in the production of the beverage plastic bottles. Replacing the 250 ml and 500 ml bottles will lead to a significant reduction in greenhouse gas emissions. FDCA (2,5-furandicarboxylic acid), the main building block of PEF, can be produced from sugars (fructose), such as from wheat, corn and sugar beets. FDCA is polymerized with plant-based mono-ethylene glycol (MEG) to create a 100% plant-based PEF polymer. When fully developed technologically, PEF can also be produced from cellulose and therefore from agricultural and forestry waste. The resulting 100% bio-based (PEF), is recyclable and degradable and has superior barrier properties to CO_2 and oxygen (extending the shelf life of products) and higher mechanical strength (leading to thinner PEF packaging which requires fewer resources) compared to PET. It also has a 12°C higher heat resistance than PET. Made from sugar cane-based components, the material helps reduce carbon dioxide emissions and leaves a smaller environmental footprint. PEF can also be used in multilayer packaging when single-layer packaging is not sufficient to guarantee the required shelf life. It has been stated that reductions of approximately 37% in greenhouse gas emissions can be achieved by replacing 250 mL PET/PEF multilayer bottles containing 10% PEF with PET/PA bottles containing 7% PA (polyamide). Most importantly, the PET/PEF system is recyclable, whereas the system containing PA is not [37].

Beverage bottles and caps made from poly hydroxy alkanoates (PHA), another fully biodegradable biopolymer, are expected to enter the market soon. The use of PHA as a packaging material is expected to increase significantly in the coming years. Additionally, three new versions of recently developed PHA resin formulations for blown film, injection molding and thermoforming were released globally for customer evaluation in 2021. Fresh produce, such as fruits and vegetables are being packaged in flexible formats (e.g. films, trays, etc.) using bioplastics [20].

Coca-Cola aims to use three million fewer tons of virgin plastic from petroleum-based sources by 2025.This will reduce virgin plastic from fossil fuels globally by approximately 20% and support the common target of becoming net zero carbon by 2050 [38].

The future of bioplastics in sustainable packaging is bright, with the potential to contribute significantly to a more sustainable and circular packaging industry. Overcoming challenges and capitalizing on growth opportunities will be key to unlocking the transformative potential of bioplastics. There is increasing pressure on flexible film lamination (paper-film, paperboard-film, aluminum-film, paperboard-aluminum, paperboard-aluminum-plastic, plastic-based rigid multilayer) applications to improve the sustainability of products. In addition, the adhesive industry is looking to use special types of biobased adhesives and is focused on reducing molecular weight components of adhesives that can more easily pass from packaging to food. Using starch as a raw material in adhesive production has advantages such as low cost and non-toxicity, as well as renewability, biodegradability, and availability. Using natural resources or bio-based materials as adhesive raw materials can help future societies become less dependent on hazardous chemicals, volatile organic compounds and petroleum-derived chemicals; In addition to promoting safer working conditions.

The colorants (dyes, inks and pigments) most used in industries today are organic molecules obtained from petrochemicals and other chemicals that may cause significant damage to the environment. Natural colorants can be classified according to their color shade (red, etc.), origin (vegetable, animal, bacterial, fungal, etc.) or chemical structure as follows: flavonoid, isoprenoid, and nitrogen heterocyclic derivatives. Colorants produced from natural sources have advantages such as environmental friendliness, biodegradability and are thought to be harmful to human health. However, natural dyes are expensive due to limited natural resources. Natural colors have been associated with 3D printing technology (manufacturing). Additionally, 3D printing is an innovative way to produce complex shapes consisting of highly reflective bio-based mixtures, bio scaffolds, and reactive mixtures [39].

4D printing is a novel and advanced technique for manufacturing based on smart materials and involves a fourth dimension [21]. The 4D printing offers various advantages such as fast growth of smart and multi-materials, more flexible and deformable structures. The 4D enables the creation of self-assembling components that minimize packaging, transportation, and assembly-related waste and also increase environmental efficiency [40, 41]. Usually, prints are made with inkjet printing, screen printing, pad printing, and 3D printing systems. For the ink production, new production methods and materials that will minimize the dependence on petrochemical resources and the adverse environmental impacts should be used. Obtaining and using natural inks or dyes can provide an advantage to food packaging such as sustainable and environmentally friendly, favoring natural dyes over synthetic dyes [42].

Sustainable polymers face two main commercialization disadvantages: A limited effective processing in the product lifespan (recycling, reuse, biodegradability and compostability) and the high production process cost. To minimize the energy required to produce sustainable polymers, every step from monomer extraction to polymer processing must be focused on the use of renewable and minimal energy, the use of green solvents/catalysts, minimization of the number of conversion steps, increasing atom economy and, where possible, new and efficient polymerization methods that are innovative and optimize the overall process [43].

Glass

Glass is a permanent material that can be endlessly recycled, reused, and refilled, thus reducing waste and conserving natural resources. Glass has the best barrier protection compared to other packaging materials and acts as a safe barrier against external influences. In addition, it is a good packaging material for foods having a long shelf life. It is transparent, has good heat resistance. Glass is widely considered a recyclable and sustainable material. Glass is produced by melting and shaping a mixture of raw materials found in nature (silica, sodium carbonate and limestone/calcium carbonate) as well as recycled glass at a high temperature. Glass bottles are satisfactorily and commonly used in packaging beverages, water, and some dry products. Although the use of glass-based packaging materials is gradually decreasing, it will remain one of the safest packaging materials in the food and beverage industry.

Glass packaging, like all other packaging materials, has limitations such as being heavier than other packaging materials, brittle, and susceptible to thermal expansion or contraction. Glass packaging is not ideal for extreme temperatures. Glass can cause physical hazards if not handled properly during handling and transportation. When glass is damaged, it may break, compromising the safety of the product it contains. Fragility and weight, the most important disadvantages of glass packaging, have been partially eliminated by using technological innovations and it is possible to produce thinner and lighter glass packaging with the same performance [7].

Product innovations that allow the reduction in the thickness and weight of glass packaging reduce CO_2 emissions by 4-5%. Glass packaging production requires a lot of energy. Industry is working intensively to reduce carbon emissions at all stages of production. Glass recycling requires less energy than producing new glass from raw materials. The *Eco2Bottle*, *Wiegand-Glas*' wine bottle, is made from 93% recycled glass and is 20 percent lighter than similar bottles. Reducing the weight of each bottle directly impacts the logistics and transportation chain by reducing CO_2 emissions. The production and consequent recycling of ever-lighter glass packaging is efficient and provides significant environmental benefits by reducing CO_2 emissions and making it economically sustainable because less raw materials, and energy are needed and lower carbon emissions produced during transportation.

Echovai has produced the world's first reusable bottle from thermally hardened lightweight glass. This reduces logistical expenses and carbon emissions. The 0.33L reusable glass bottle has been introduced, with a weight reduction of around a third compared to the standard bottles (300 grams): Carbon emissions per bottle are only a quarter of that of the standard 0.33 lt reusable bottle [44]. Their reusability, recyclability, retention of product quality and longevity make them an excellent choice for those who want to reduce their carbon footprint. Reusable glass bottles have 85% less carbon emissions than disposable bottles, 75% less than disposable PET bottles, and 57% less than aluminum cans [45].

The glass industry aims and works towards a low-carbon future. It continues its work to minimize carbon emissions under the vision title "Ovens for the Future (F4F)". Investment should be made in low energy and low gas emission furnaces. It will be a major step to convert 50% or more of the furnaces used in glass packaging production into hybrid furnaces that use 80% renewable energy [46].

Metal

Metals used in food packaging include steel, tin and aluminum (cans, bottles, foil, and closures). Metal materials have advantages of durability (heat, light-UV, breakage-puncture), high barrier, durability and recyclability (easy to separate due to their magnetic nature) Recycled metals can be easily remelted and used to mould new packages [47]. However, disadvantages may include weight, processing costs and energy used at the same time, tin and aluminum from mining to production have their own life cycle considerations that need to be taken into account and carefully considered for environmental impact. For sustainability purposes, it is important that the production and recycling processes of metal packaging are based on environmentally friendly methods. Additionally, the design of the packaging should also be considered to reduce waste and facilitate recycling. Metal is widely recyclable. The production and recycling of metal is energy intensive [48]. Due to their capacity to be recycled, these materials are crucial parts of contemporary food packaging solutions since they not only guarantee the preservation of food quality and safety but also support sustainability initiatives [49].

Among all packaging metals, aluminum is the most used in packaging due to its structure. Aluminum's notable features include its low cost, light weight, flexibility, recyclability, and high heat resistance. Aluminum is a lightweight and corrosion-resistant metal. Aluminum is a very good conductor of electricity. Aluminum foil is used in closures, as a wrap and aluminum is used for beverage cans, tubs and trays, and blister packages that protect tablets and capsules, and areas as a layer in multi-layer structures for its barrier properties. It's easy shaping feature and decorative potential make aluminum a preferred material [48].

Steel is a durable, heavy and strong metal. Although steel is resistant to corrosive effects, it must be made more durable with coatings. Steel is used in the food industry as cans, g metal lids, metal drums and other container types [48].

Tin is a widely used material in metal plating. This coating is often used to coat steel to prevent corrosion when used for foodstuffs. [48]. Metal containers are extremely sustainable as they are the packaging material with the highest recycling rates worldwide, with 80% of tin packaging in Europe being recycled. This reduces energy consumption and eliminates raw material needs. Additionally, metal packaging helps reduce carbon emissions and contributes to the circular economy. In order to ensure the sustainability of metal packaging, features such as embossing, easy opening and lighter weight have been added [50].

INCREASING SUSTAINABILITY and INNOVATIVE FOOD PACKAGING MATERIALS

The main materials used for sustainable packaging are paper, paperboard, and corrugated fiberboard, bioplastic materials, glass, and metals. These materials are usually obtained from renewable resources, and including polymers obtained from microorganisms. These materials are recyclable, and/or reusable packaging that reduces disposable packaging waste. The efficient and effective practice of recycling can protect the environment from the pollution that may arise during the extraction of materials that are used in packaging industries [51]. With advancement of technologies, sustainable packaging has emerged in response to consumer preferences and environmental obligations. Studies on new techniques and new sustainable materials in packaging are increasing. Both new and higher-performance bioplastics are described as a breakthrough technology for sustainable packaging (Table 1).

Table 1. Top 20 sustainable packaging technologies by impact on sustainability and likelihood of adoption between 2018 and 2028 (adapted from [20])

Category	Technology
Recycling	• Near infrared process formality recovery • Deinking waste cardboard • Recyclable or biodegradable packaging • Design for recycling (airbags) • Effective cleaning of plastic waste for reuse Improved separation of multipolymer structures • Plastic-digesting bacteria
Innovative materials	• New biopolymers • Natural barrier coatings • Higher performance bioplastic • Edible packaging (bowls). • compostable packaging • Mono material barrier films
Design	• Smart tagging • Lightweight available packages • Hybrid meal delivery boxes. • Antimicrobial nanotechnology in active packaging
Other	• Big data analytics and blockchain • Innovation in covers • Sustainable protective packaging for transit and e-commerce • Free market packaging waste trade • Extended waste to energy schemes • Plates, trays and portion boxes made of corn starch, an alternative to polystyrene • Popcorn (rather than plastic cushioning) is a sustainable packaging option.

One of the currently most active research and development areas in packaging is bioplastics. Alternative cellulose-based feedstocks, such as bioplastics derived from bacteria and agricultural waste and other plant materials, are constantly being developed. For example, researchers Parrino, Fidalgo [52] have shown that polycarbonate can be produced from the synthesis of limonene, an extract from orange peels, and carbon dioxide. CNs are likely to be one of the most important new materials contributing to sustainable packaging. The versatility of CNs to serve as barrier films, coatings, reinforcements or additives for plastics raises the possibility they will become an important new packaging material. Additionally, the potential of PLA-based nanocomposite films to be used as packaging materials to extend the shelf life of water-sensitive food products has recently been demonstrated. Other natural coatings are expected to improve the properties of paper cups and providing durability to paper and corrugated fiberboard [27]. Another interesting innovation is packaging that is intended to be edible. The production of edible films with increased barrier properties by polymerizing biopolymers such as Chitosan, Whey Protein Isolate and Casein thru addition of cellulose nanocrystallites (whiskers) is being investigated [20]. New and high-performance bioplastics, that replace traditional bioplastics, will have an important place in sustainable packaging. Innovative materials continue to be developed at a rapid rate.

SUSTAINABLE FOOD PACKAGING REGULATIONS

Several countries have introduced regulations to reduce packaging waste and promote environmentally friendly alternatives. In general, the trend towards sustainable food packaging legislation and regulations is expected to continue and that more countries and regions introducing policies are taking measures to reduce waste and promote the promotion of a circular economy. The majority of most laws in the countries examined in the study also address the following end-to-end issues: packaging requirements, recyclability, expected main uses of packaging, packaging chain, including collection and sorting plans, schedules and determination of reuse - or recycling goals.

Regulations on Sustainable Food Packaging Materials in Different Countries

Regulations on sustainable food packaging materials vary across different countries, including Türkiye, EU, the US, the UK, Canada, and Japan (Table 2).

Türkiye's national government and its environmental agencies have begun taking measures to curb the consumption of certain single-use plastics through economic tools such as taxes, fees and container deposit systems, they are still not addressing the amount of imported waste entering the country. This regulation, entitled “Geri Kazanım Katılım Payına İlişkin Yönetmelik”, introduced a recycling contribution fee (known as GEKAP) on the packaging of products sold domestically in early 2020 (Regulation 30995 on Recycling Contribution Rate). Environmental Law No. 2872 and Regulation 30829, Zero Waste Regulation, published in 2019, sets the goal of developing a zero-waste management system. Environmental Law No. 7153 – The procedures and principles regarding the collection of fees for plastic bags (2019). Some examples of recycling contribution shares for 2024 are: 0.25 TRY for each plastic bag, 19 TRY for each rubber tire, 4 TRY per kilogram for plastic packaging (except beverage containers and plastic bags), etc." According to Ordinance 30283 on the control of packaging waste (repealed) packaging must be “reused, recycled, recovered and designed and manufactured in a way that causes the least harm to the environment in the management and disposal phases that these processes include”. Türkiye's National Waste Management and Action Plan sets targets for diverting waste from landfills and increasing its recycling targets, and is in line with EU Directive 2015/720, which targets plastic bag consumption. The general legal framework for the regulation of packaging and plastic waste is established by Environmental Law No. 2872 [53].

The European Parliament and the Council regulate the rules for environmentally friendly food packaging in the EU. In order to make all plastic packaging recyclable by 2030, the European Strategy for Plastics was adopted in January 2018. Member states have agreed to adopt stricter regulations by 2030 (Table 2).

Table 2. Regulations on sustainable packaging materials in some countries [54].

Country	Regulations
Türkiye	• Regulation 30995 on Recycling Contribution Rate, recycling contribution fee – GEKAP • Environmental Law No. 2872, (2019) • Regulation 30829, Zero Waste Regulation, (2019)
European Union	• The heart of EC legislation on packaging and packaging waste is Directive 94/62/EC (Directive 94/62/EC, 1994). • Regulation (EC) No. 1935/2004 and Regulation (EC) No. 2023/2006 on food contact/packaging materials • Regulation (EC) 282/2008 on recycled plastic materials for food packaging • Directive (EU) 2018/852 amendments of Directive 94/62/EC on packaging and packaging waste EPR EU’s Circular Economy (2020) • Directive (EU) 2019/904 on single-use plastics • EN 13427:2004d Requirements in the field of packaging and packaging waste • EN 13428:2004d Prevention through source reduction • EN 13429:2004d reuse; EN 13430:2004d recovered through material recycling • EN 13431:2004d requirements for packaging energy recovery • EN 13432:2004d requirements for packaging recoverable through composting and biodegradation.
United States of America	• Federal Food, Drug, and Cosmetic Act (FDCA) (Title 21) (1938) • Guidance for Industry: Use of Recycled Plastics in Food Packaging: Chemistry Considerations (2021)
United Kingdom	• Producer Responsibility Obligations (Packaging Waste) Regulations (2007) • The Plastic Packaging Tax (2022) • Packaging (Essential Requirements) Regulations (2015) • Deposit Return Scheme (2023)
Canada	• Ban on single-use plastic items • Canadian Standards Association developed standard • CAN/BNQ-0017-088 for compostable plastics
Japan	• Food Sanitation Act (1947) • Plastic Resource Circulation Act (Act No. 60 of 2021) • Containers and Packaging Recycling Act (1995)

Less packaging and restrictions on certain packaging formats the agreement sets packaging reduction targets (5% by 2030, 10% by 2035 and 15% by 2040) and obliges EU countries to reduce the amount of plastic packaging waste in particular. Ban on the use of "forever chemicals" In order to prevent adverse health effects. Final distributors of take-away drinks and food in the catering industry would be obliged to offer consumers the option of bringing their own container. They would also have to strive to offer 10% of products in a reusable packaging format by 2030[54].

United States Federal Regulations:

- The US Environmental Protection Agency (EPA) promotes sustainable packaging through initiatives like the Sustainable Materials Management Program (SMM), which encourages the use and reuse of materials over their life cycles [55].
- State-Level Regulations: States such as California, New York, and Oregon have enacted laws to ban single-use plastic bags and introduced Extended Producer Responsibility (EPR) legislation to manage packaging waste responsibly [55, 56].
- The US FDA believes that as long as the recycled polymer is kept separated from the food by a reliable barrier of virgin polymer or other suitable material such as aluminum foil, there is no need to worry about possible migration of contaminants into food use. The US FDA has issued safety notices for PET and HDPE containers with a layer of recycled material and a layer of virgin material that comes into contact with food. While EC 10/2011 sets criteria for the composition of new plastic materials, the separate regulation of EC 2022/1616 sets out recycled plastic materials and items intended to come into contact with food (EUR-Lex, 2022).

The UK's environmental packaging regulations aim to promote more sustainable packaging and reduce waste sent to landfill:

- United Kingdom Extended Producer Responsibility (EPR): The UK has implemented EPR policies, requiring businesses to collect data on their packaging to comply with regulations and promote sustainable practices.
- Plastic Packaging Tax: The UK introduced a tax on plastic packaging with less than 30% recycled content to incentivize the use of recycled materials and reduce waste.
- Single-Use Plastic Bans: The UK has banned certain single-use plastic items and implemented policies to reduce plastic waste and promote recycling [57].

Regulations in Canada;

- Canada Single-Use Plastics Prohibition Regulations (SUPPR): Canada aims to achieve zero plastic waste by 2030 through the prohibition of manufacturing, importing, and selling many single-use plastic items [56].
- Extended Producer Responsibility (EPR): Provinces like Ontario and British Columbia have implemented EPR programs for packaging materials, requiring businesses to take responsibility for recovering and recycling their packaging waste [55].

Japanese Regulations:

- Japan Food Sanitation Law (1947): Japan has regulations focusing on packaging and product safety, ensuring that food packaging materials meet certain standards [54].
- Containers and Packaging Recycling Act (1995): This act promotes the recycling of packaging materials and encourages sustainable practices in the packaging industry [54].

There is no international treaty that imposes legal obligations on contracting states regarding sustainability. Several international bodies - from the General Assembly itself to the United Nations Environment Program (UNEP) to the United Nations Development Program (UNDP) - cooperate and work with states and non-state actors on sustainability issues; there is no international agency mandated with monitoring and enforcement powers. Regulations alone are obviously not enough. Through strict enforcement and monitoring, national and supranational entities, regional authorities, companies, communities and individuals become responsible actors.

These regulations highlight the global commitment to reducing packaging waste and promoting sustainable practices in the food packaging industry (Table 2).

FOOD COMPANIES AND SUSTAINABILITY STUDIES

According to the SÜTAŞ 2022 Sustainability Report

1. Under the headings of Carbon Management and climate change, 80% of the needs of their production facilities were met by renewable energy sources.
2. They grew approximately 43 thousand tons of organic matter in their fields.
3. They carried out R&D studies by breeding productive breeds on their farms.
4. Sustainable dairy farming training was provided to approximately 19 thousand employees working in the companies.
5. They reduced the amount of plastic material they used in their packaging by 153 tons (Sütaş Sustainability Reports, 2022).

According to ŞİŞECAM 2022 Sustainability Report (Table 3)

1. Approximately 7 million m^3 of water was recycled.
2. Obtaining demineralized water
3. The project of collecting and recycling packaging glass waste is being carried out.
4. Thanks to waste glass collection projects, between 500 and 1000 tons of glass were recycled.
5. Low-e coated glass has been developed, making it possible to control heat and light.
6. Household items are produced from 100% recycled glass materials.
7. Primary school students were raised with recycling training.

8. Approximately 5 million people were reached through social media and information was given about the sustainability of glass (Sustainability Reports, 2022).

Table 3. Packaging product examples for Şişecam and Ardgah Group sustainability efforts

Company Name	Packaging Type	Product Type
ŞİŞECAM	Glass	Low E-Glass Products
		Antimicrobial V-Block Coating
		Solar Panel Glasses
		Lightweight Glass Packaging
		Glass fiber
ARDGAH	Glass	Efficient Oven
		NextGen Hybrid Oven

According to ARDGAH GLASS 2022 Sustainability Report (Table 3)

Ardgah Glass examples of packaging products for sustainability studies continues to work on the NextGen Hybrid Furnace, which aims to reduce GGE by 60 percent [58].

CONCLUSION

Sustainability is becoming ever more important across all aspects of the economy. Sustainable packaging is an active development and research area with increasingly innovative ideas. Growing consumer demand around the globe for sustainability initiatives and emerging regulations will continue to drive packaging towards sustainability. Companies are under pressure to re-think and re-design their packaging systems. Bio-based materials such as paper and board and bioplastics are ideally positioned to capture some of this market growth. However, there are still challenges to fully realize the replacement of petroleum-derived packaging with bio-based packaging. It is anticipated that ongoing research and technological advances, innovative new materials, consumer education, improvements in recycling and increased commercial availability will continue to contribute to increased acceptance of these alternative materials. Many countries and regions have implemented regulations that require sustainable eco-friendly alternatives packaging materials or set targets to cut down on packaging waste.

Sustainable packaging and may bring us closer to a more sustainable future. Although there are many benefits to eco-friendly or sustainable food packaging, the cost of switching to these food packaging solutions can be expensive, especially for many small businesses. It can lead to higher costs in the production and other parts of the operation. Whether consumers are willing to compromise and pay more poses a clear challenge for companies. Sustainable packaging should remain as broadly encompassing as possible.

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1. Çalışmalar A4 boyutunda hazırlanmalı, üstten 2.45 cm, alttan 2.45 cm, sağ ve soldan 1.75 cm boşluk bırakılmalı ve tek kolon olarak hazırlanmalıdır. Metin çift satır aralıklı yazılmalı, paragraflar arasında tek satır boşluk bırakılmalıdır. Metinde bütün satırlar (sürekli) numaralandırılmalıdır.

2. Çalışma başlığı 14 punto Arial, koyu, küçük harflerle ve ortalanmış olarak yazılmalıdır. Başlıktan sonra bir satır boşluk bırakılmalı (11 punto); yazar isimleri (yalnızca ilk harfler büyük) 10 punto Arial ve ortalanmış olarak verilmelidir. Yazarların adresleri, telefon ve faks bilgileri ile yazışmalardan sorumlu yazarın e-posta adresi hemen alt satırda 9 punto Arial, ilk harfler büyük olacak şekilde ve ortalanmış olarak yazılmalıdır. Yazarların çalıştıkları kuruluşlar (ve/veya adresler) farklı ise her bir yazar isminin sonuna rakamlarla üst indis konulmalıdır.

3. Metin içindeki kısımların başlıkları (ÖZ, ABSTRACT, GİRİŞ vb.) 10 punto Arial ve koyu olarak büyük harflerle yazılmalı, başlıktan sonra bir satır boşluk bırakılarak metine geçilmelidir. Alt başlıklarda ilk harfler büyük, 10 punto Arial ve koyu yazı karakteri kullanılmalıdır. ÖZ'ün altına bir satır boşluk bırakıldıktan sonra en fazla 5 adet Anahtar Kelime konmalıdır. Anahtar Kelimelerden sonra bir satır boşluk bırakılarak İngilizce başlık ve altına ABSTRACT ve Keywords yazılmalıdır. Bir satır boşluk bırakılarak ana metine geçilmelidir.

4. Ana metin 9.5 punto Arial olarak hazırlanmalıdır.

5. Çalışma başlıca şu kısımlardan oluşmalıdır: Başlık, Yazar İsimleri, Adresleri, İletişim Bilgileri, Yazışmalardan Sorumlu Yazarın E-posta adresi, Öz, Abstract, Ana Metin (Giriş, Materyal ve Metot, Bulgular ve Tartışma, Sonuç), Teşekkür (gerekiyorsa), Kısaltmalar (gerekiyorsa), Kaynaklar.

6. Öz ve Abstract 250 kelimeyi geçmemeli, çalışmanın amacını, metodunu ve önemli sonuçlarını içermelidir. Öz tek paragraf olarak yazılmalı ve öz içinde kaynaklara atıf yapılmamalıdır.

7. Çalışma içerisinde geçen mikroorganizma isimleri ile Latince ifade ve isimler italik olarak yazılmalı ve kısaltmalarda uluslararası yazım kuralları göz önünde bulundurulmalıdır.

8. Tablo başlıkları tablonun üstüne, şekil başlıkları ise şeklin altına yazılmalı ve numaralandırılmalıdır. Kullanılan tablo ve şekillere metin içinde mutlaka atıf yapılmalıdır. Metin içinde geçen veriler tablo ve şekillerin tekrarı olmamalıdır. Tablo ve şekillerin başlıkları içerikleriyle uyumlu ve anlaşılabilir olmalıdır. Şekiller ve resimlerin yüksek çözünürlükte olmasına dikkat edilmelidir. Resimler (ve gerekiyorsa Şekiller) *.jpg formatında metin içerisinde yer almalıdır.

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- Manuscripts to be submitted should be free from any spelling or grammatical error.
- Authors must guarantee that the submitted manuscript is not published anywhere previously and will not be submitted to anywhere before the editorial board makes a final decision on the manuscript.
- The editorial board is authorized to make necessary changes in manuscripts accepted for publication.

Peer review policy

Manuscripts pass through initial screening in the editorial office followed by internal review by Editors. After the first evaluation, manuscripts are double-blind-reviewed by a peer review system involving at least two independent reviewers to ensure high quality of manuscripts accepted for publication. The Editors have the right to decline formal review of a manuscript if it is (i) on a topic outside the scope of the Journal, (ii) lacking technical merit, (iii) fragmentary and providing marginally incremental results or (iv) poorly written.

Publication fee

There is a 1000 TL submission fee for Turkish manuscripts submitted after February 1, 2024. This fee may not be waived. 750 TL fee is charged for articles submitted to the journal in English.

Ethics Statement

Detailed information about journal publication policy, evaluation of manuscripts and ethical issues can be found in the Ethics Statement section.

Preparation of a manuscript

1. Manuscripts should be prepared in A4 size, and the text must be prepared in a single column format. The text must be double-spaced, and a single space should be left between paragraphs. All lines and pages must be continuously numbered.

2. The title must be 14pt Arial, bold, small letters and centered. A blank line should be left after the title, and the names of authors should be given in 10pt Arial and centered. In addition to each author's contact address, the phone and fax numbers and e-mail address of the corresponding author should be provided. If the institutions of the authors are different, superscript numbers should be used to indicate their addresses.

3. The headings (e.g. Abstract, Introduction, Materials and Methods etc.) must be 10pt Arial, and should be typed in bold capital letters. Each heading should appear on its own separate line. A blank line should be left after each heading. A list of keywords, a maximum of 5, should be provided below the abstract section of the manuscript.

4. The main text should be prepared in 9.5pt Arial.

5. Typical articles mainly consist of the following divisions: Title, Author Names, Addresses, Contact Information, Corresponding author's e-mail address, Abstract, Main text (Introduction, Materials and Methods, Results and Discussion, Conclusions), Acknowledgements (if necessary), Abbreviations (if necessary) and References.

6. The abstract should not exceed 250 words, and the main purpose and method and the most significant result and conclusion should be presented in the abstract. The abstract should be prepared as a single paragraph, and should not include any citation.

7. Latin names in the text should be in italics, and names and abbreviations should follow international rules. If abbreviations that are not standard are unavoidable, they must be defined at their first mention in the text. Consistency of abbreviations throughout the article must be ensured. Internationally accepted rules and conventions must be followed, and the international system of units (SI) must be used. If other units are mentioned, their equivalents in SI must be provided.

8. Table headings should be on the top of each table and figure captions below each figure. Each table or figure must be numbered consecutively in accordance with their appearance in the text. All figures and tables should be cited in the text. The data presented in the tables and figures should not be repeated in the text. Table headings and figure captions should be self-explanatory. Figures and pictures must be provided in high resolution, and pictures (and, if necessary figures) should be included in the text as *. jpg format.

9. References in the text should be cited in numbers in square brackets [1] and details of the citations must be provided in the Literature or References section with their respective numbers.

10. Mathematical equations should be numbered and cited in the text.

11. References should be given according to the APA manual of style. The following formats should be used for the details of cited references, and the journal names must be typed in italics. References to the Web addresses (if necessary, the official web pages should be preferred) must include full web address and the date of access.

Article

[1] Güzeler, N., Kaçar, A., Say, D. (2011). Effect of milk powder, maltodextrin and polydextrose use on physical and sensory properties of low calorie ice cream during storage. *Akademik Gıda,* 9(2), 6-12.

Book

[2] Kilic, S. (2001). Lactic Acid Bacteria in Dairy Industry. Ege University Faculty of Agriculture Publications, Ege University Press, Bornova, Izmir, Turkey.

Book Chapter

[3] Gibson, G.R., Saavedra, J.M., MacFarlane, S., MacFarlane, G.T. (1997). Probiotics and Intestinal Infections. In Probiotics 2: Applications and Practical Aspects, Edited by R. Fuller, Chapman & Hall, 2-6 Boundary Row, London, England, 212p.

Proceedings of the Congress-Symposium

[4] Gursoy, O., Akdemir, O., Hepbasli, A., Kinik, O. (2004). Recent situation of energy consumption in dairy industry in Turkey. *International Dairy Symposium: Recent Developments in Dairy Science and Technology*, May 24-28, 2004, Isparta, Turkey, Book of Proceedings, 10-16p.

12. A list of the corrections requested by the referees must be provided by the authors, and it must be sent to the editorial office.

13. Studies that are not prepared in accordance with the rules above will not be considered for evaluation.

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Etik Beyanı

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Yayın Politikası

Akademik Gıda dergisine gönderilen tüm makaleler Dergi Editörleri için Davranış Kuralları ve En İyi Uygulama Kılavuzları ve Dergi Yayıncıları için Davranış Kurallarında (Code of Conduct and Best Practice Guidelines for Journal Editors and Code of Conduct for Journal Publishers) belirtilen Genel Kılavuzlara uygun olarak değerlendirilmektedir. Bilimsel yazılar dergiye gönderilmeden önce derginin Yazım Kurallarının okunmasını önemle tavsiye ederiz. Yazarlar aynı zamanda Avrupa Bilim Editörleri Birliği'nin (EASE) (European Association of Science Editors) İngilizce olarak basılacak makaleler için "Bilimsel Makalelerin Yazarları ve Çevirmenleri İçin Rehber"e uymalıdır. Yazarlar, insan veya hayvan verilerini içeren araştırmaları için Uluslararası Tıp Dergisi Editörleri Komitesinin (International Committee of Medical Journal Editors) önerilerini takip etmelidir.

Makalelerin Değerlendirilmesi

Dergiye gönderilen tüm makaleler, bilimsel içeriklerinin özgünlüğü ve kalitesi ölçütlerine göre değerlendirilir.

- Dergiye gönderilen tüm yazılar, ilk olarak yayın ofisindeki (teknik ve genel kalite değerlendirilmesi açısından) eleme işleminden geçer ve ardından teknik ve bilimsel editörler tarafından değerlendirilir.
- İlk değerlendirmeden sonra, editörler (i) dergi kapsamı dışında kalan bir konu hakkında hazırlanmış makaleleri (ii) teknik olarak eksik/yetersiz makaleleri, (iii) kısmi ve marjinal artan sonuçları içeren makaleleri veya (iv) kötü yazılmış makaleleri reddetme hakkına sahiptir.
- İlk inceleme sonucunda makalenin ileri değerlendirme için uygun olduğuna karar verilirse, dergide yayımlanmak üzere kaliteli makalelerin seçimini yapmak amacıyla, makaleler çift-körlü (hakemin ve yazar/yazarların birbirlerini görmedikleri) değerlendirme sistemi ile en az iki bağımsız hakemden oluşan bir değerlendirme sürecinde bilimsel incelemeye alınır.
- Hakemler tarafından talep edilirse, makalenin hakem görüşleri doğrultusunda yazarlar tarafından revize edilmiş versiyonu orijinal hakemler tarafından tekrar değerlendirilir. Değerlendirmelerin ardından editörler hakem önerileri doğrultusunda makale hakkındaki nihai kararlarını verirler. Gerekirse editörler, hakemlerin istedikleri tüm şartların yerine getirilmesi için yazarlardan ilave revizyon isteyebilir.
- Kabul edilen makalelerin son versiyonu, yayın öncesi taslağın (galley proof) hazırlanması için teknik editörlere gönderilir. Yazarlardan, makalelerinin dizgisi hazırlanmış taslaklarını son kontrol için yayın öncesinde incelemeleri istenir.
- Tüm makaleler, nihai formlarında DOI numarası almış ve çevrimiçi olarak pdf dosyaları halinde yayımlanır. İlgili veritabanlarında bu şekilde indekslenir.

Yayın Ücreti

Akademik Gıda dergisinde makalelerin yayınlanması için herhangi bir yayın ücreti talep edilmemektedir.

Gizlilik

Editörler, Akademik Gıda'ya gönderilen tüm makaleleri tam bir gizlilikle ele alır. Editörler, hakemler haricinde, COPE tavsiyelerine uyulmadığı takdirde, üçüncü şahıslara makale ile ilgili hiçbir bilgi vermezler. Yayınlanmak üzere dergiye gönderilen makaleler hakemler için de gizlidir ve bilimsel değerlendirme için aldıkları makalelerin herhangi bir bölümünü üçüncü şahıslarla paylaşmalarına veya dağıtmalarına izin verilmez. Suiistimal şüphesi olduğunda, hakemlerin derhal gizli bir şekilde yayın ofisine başvurmaları önerilir. Hakemler ayrıca, Dergi Editörleri İçin Davranış Kuralları ve En İyi Uygulama Kuralları ile Dergi Yayıncıları için Davranış Kuralları'nı (Code of Conduct and Best Practice Guidelines for Journal Editors and Code of Conduct for Journal Publishers) takip ederek editöre gizli yorumlarında belirli bir eylem önerebilirler.

Akademik Gıda, çift-kör bir hakem inceleme süreci yürütür, yani çalışmanın eleştirel değerlendirmesini sağlamak için hakemlerin isimleri gizlidir. Hakemlerden, raporlarında adlarını veya irtibat bilgilerini açıklamamaları istenir. Hakem raporları yazarlara gönderilemeden önce bu açıdan kontrol edilir.

Yazarlık

Bir yazar, bir araştırmanın fikrine veya tasarımına, verilerin elde edilmesine, verilerin analizine veya yorumlanmasına büyük ölçüde katkıda bulunan, makalenin hazırlanmasında, yazılmasında veya gözden geçirilmesinde entelektüel içeriğe eleştirel katkı yapan bireydir. Katkıda bulunanlar diğer kişiler makalenin Teşekkür bölümünde belirtilmelidir ve çalışmanın yazarı olarak kabul edilemez. Tüm yazarların doğru ve tam isimleri ile ORCID kimlikleri dergiye gönderilen makalenin başlık sayfasında yer almalıdır. Yazarların isimlerinin yanında çalıştıkları kurumlar ve yazışmalardan sorumlu yazarın geçerli bir adresi verilmelidir. Yazışmalardan sorumlu yazarın telefon ve faks numaraları ile e-posta adresi makalenin ilk sayfasında belirtilmelidir. Tüm yazarlar, gönderilen makalenin daha önce herhangi bir yerde yayınlanmadığını ve makale hakkında Akademik Gıda dergisi nihai bir karar vermeden önce makaleyi başka bir dergiye göndermeyeceklerini garanti etmelidir.

Destekleyen/Finans Sağlayan Kuruluşlar

Araştırmanın tüm finans kaynaklarına ilişkin detaylar, Teşekkür bölümünde belirtilmelidir. Yazarlar, resmi finansman kurum/larının tam isimlerini ve proje/hibe numaralarını belirtmelidir.

Yazarlarda Değişiklik

Makalenin Akademik Gıda'ya sunulmasından sonra yazar isimlerinde değişiklik ancak revizyon sırasında gerekli olan ek çalışmalar durumunda olabilir. Makalenin yayına kabul edilmesinden sonra herhangi bir değişikliğe izin verilmez. Yazarlıktaki değişiklik, hakem görüşlerine verilen cevaplar sırasında yazışmalarda belirtilmeli ve tüm yazarlar tarafından kabul edilmelidir. Yazışmalardan sorumlu yazar, yazarların sırası da dahil olmak üzere makalenin revize edilmiş versiyonundaki değişikliklerden sorumludur.

Çalışma Verilerinde Düzeltme

Yayınlanan verilerin doğruluğundan tüm yazarlar sorumlu olmalıdır. Verilerin düzeltilmesi için, yazışmalardan sorumlu yazardan yayın öncesi taslağı (galley proof) incelemesi ve makalenin yayınlanmasından 4 gün önce dikkatlice düzeltmesi istenir.

Makalenin Geri Çekilmesi

Bir makalenin geri çekilmesi, gönderim veya yayın hatalarını düzeltmek için kullanılır. Yazarlar makaleyi geri çekebilir ve bu durumda Yayın Etiği Komitesi (COPE) Geri Çekme Kurallarına [(COPE) retraction guidelines] uymalıdır. Tekrarlanan veya benzerlik oranı yüksek bir yayın, verilerin hileli kullanımı, intihal veya etik dışı araştırma yapılması durumunda, makale editör tarafından geri çekilecek ve geri çekilen makale linklerine bağlantı korunacak ancak elektronik veri tabanına (makale sayfasına) bir geri çekme bildirimi eklenecektir.

Etik Hususlar

Çıkar çatışması:

- Yazar/lar başvuru sırasında herhangi bir çıkar çatışması varsa beyan etmelidir. Yazar/ların başvuru sırasında bilimsel değerlendirme için en az üç potansiyel hakem önermeleri istenir. Önerilen hakemler çalışma arkadaşları, ortak çalıştıkları kişiler veya çalıştıkları kurumların üyeleri olamazlar.
- Hakemler makaleyi değerlendirmelerini önleyen herhangi bir çıkar çatışması olması durumunda Editörleri bilgilendirmesi ve bu konuda COPE kurallarına uyması tavsiye edilmektedir.
- Editörler Kurulu üyeleri veya kurul üyelerinin ortak çalıştıkları kişiler tarafından dergiye gönderilen makaleler için, değerlendirme sırasındaki önyargıları en aza indirgemek amacıyla, değerlendirme süreci ilgili kurul üyelerini dışarıda tutacak şekilde değiştirilerek uygulanır.
- Düzeltmeler (revizyonlar) sırasında, editörler Dergi Editörleri İçin Davranış Kuralları ile En İyi Uygulama Kılavuzu ve Dergi Yayıncıları İçin Davranış Kurallarını (Code of Conduct and Best Practice Guidelines for Journal Editors and Code of Conduct for Journal Publishers) takip ederler.

İnsan denekleri, hayvan veya bitki içeren araştırmalar

- Araştırmanın insan denekleri veya hayvanları içermesi durumunda, yazarların Uluslararası Tıp Dergisi Editörleri Komitesinin (the International Committee of Medical Journal Editors) yönergelerini izlemeleri önerilir.
- İnsan denekleri içeren çalışmalarda, deneklerin çalışmaya katılmak için imzaladıkları onamlar yazarlar tarafından sağlanmalıdır. 18 yaşın altındaki deneklerin çalışmaya katılmaları için ebeveyn veya velileri tarafından izin verilmelidir.
- Test edilen tüm denekler için, makalenin, ilgili kurallara ve/veya uygun izinlere veya lisanslara uyumunu gösteren belgelerin sunulması gerekir.
- Hayvanlar üzerinde yapılacak her türlü araştırma kurumsal, ulusal veya uluslararası kurallara uygun olmalı ve etik kurul tarafından onaylanmalıdır.
- Bitki materyallerinin toplanması dahil, bitkiler üzerinde yapılan deneysel araştırmalar, kurumsal, ulusal veya uluslararası kurallara uygun olmalıdır.
- Saha çalışmaları yerel mevzuata uygun olarak yapılmalı ve uygun izinleri ve/veya lisansları belirten bir açıklama makalede yer almalıdır.

Yayın suistimali

- Akademik Gıda dergisi, Dergi Editörleri İçin Davranış Kuralları ile En İyi Uygulama Kılavuzları ve Dergi Yayıncıları İçin Davranış Kurallarını (Code of Conduct and Best Practice Guidelines for Journal Editors and Code of Conduct for Journal Publishers) takip eder.
- Makalenin aynı anda birden fazla dergiye gönderilmesi, intihal, yayınlanmış makalenin yeniden yayınlanması, etik kuralların ihlali vb. şüpheli bir suiistimal durumunda, araştırmacılar, hakemler veya okuyucular Yayın Ofisi (ogursoy@yahoo.com) ile iletişime geçmeye teşvik edilir.
- Makaledeki benzerlik oranı tek bir kaynaktan %10'dan fazla olmamak üzere en fazla %25 ile sınırlandırılmıştır. Bu koşula uymayan makaleler reddedilir. Bu şartların ihlal edilmesi durumunda, COPE (COPE recommendations) tavsiyeleri izlenecek ve ilgili tüm taraflara bildirilecektir.

Telif Hakkı

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Ethics and Publication Malpractice Statement

Akademik GIDA® is a peer-reviewed journal where original research and review articles are published quarterly by Sidas Media Agency Advertisement Consultation Ltd. (Cankaya, Izmir, Turkey) in the field of food science and technology. In order to improve the overall scientific quality of the journal, following guidelines have been established by the publisher.

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Peer Review

All contributions are evaluated according to the criteria of originality and quality of their scientific content.

- All manuscripts pass through an initial screening process (technical and overall quality evaluation) in the editorial office followed by an internal review by the technical and scientific editors.
- After the first evaluation, editors have the right to decline formal review of a manuscript if it is (i) on a topic outside the scope of the Journal, (ii) lacking technical merit, (iii) fragmentary and providing marginally incremental results or (iv) poorly written.
- If the manuscript is considered suitable for further evaluation, manuscripts are double-blind-reviewed by a peer review system involving at least two independent reviewers to ensure high quality of manuscripts accepted for publication.
- If requested, the revised version is evaluated by the reviewers, and editors make a decision about final acceptance based on their suggestions. If necessary, further revision can be asked for to fulfil all the requirements of the reviewers.
- The final version is then sent to the technical editor in order to produce a galley proof, and the authors receive this proof for final check before publishing.
- All manuscripts are posted online as pdf files in their final form, indexed in databases with the assigned DOI numbers.

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An author is an individual who substantially contributed to the idea or design of a research, acquisition of data, analysis or interpretation of data, was involved in drafting, writing or revising the manuscript critically for important intellectual content. Other contributors should be mentioned in the Acknowledgements section of the manuscript and cannot be considered as authors of the study. Correct and full names of all authors and their ORCID IDs should be on the title page of the manuscript. Names of authors must be supplemented with their affiliations and a valid address of the corresponding author. The phone and fax numbers and e-mail address of the corresponding author should be stated in the first page of the manuscript. All authors must guarantee that the submitted manuscript is not published anywhere previously and will not be submitted to anywhere before the editorial board makes a final decision on the manuscript.

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Details for all funding sources of the research should be stated in the Acknowledgements. Authors should provide the full official funding agency name(s) and grant number(s).

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All authors should be responsible for the accuracy of the published data. For the correction of data, the corresponding author receives the galley proof of the paper and is asked to correct it carefully within 4 days before publication.

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A retraction of an article is used to correct errors in submission or publication. Authors can retract the paper and should follow the Committee on Publication Ethics (COPE) retraction guidelines. In case of a duplicate or overlapping publication, fraudulent use of data, plagiarism or unethical research, the paper will be retracted by the editor, and a retraction notice will be included into the electronic database while all links to the retracted article will be maintained.

Ethical Considerations

Conflict of interest:

- Authors should declare any conflict of interest in their submission form. Authors are requested to suggest at least three potential reviewers before submission, and these reviewers cannot be their colleagues, collaborators or members of their institutions.
- Reviewers should notify the editors on any conflict of interest which prevents them from reviewing the paper, and they are recommended to follow the COPE guidelines.
- For the manuscripts submitted by the members of the Editorial Board or their collaborators, peer reviewing is modified to exclude them from the entire evaluation process in order to minimize any bias during the evaluation.
- During revision, the editors follow the Code of Conduct and Best Practice Guidelines for Journal Editors and Code of Conduct for Journal Publishers.

Research involving human subjects, animals or plants:

- If the research involves humans or animals, the authors are recommended to follow the guidelines of the International Committee of Medical Journal Editors.
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