DRYING OF BLUEBERRY (*Vaccinium* spp.) AND CORNELIAN CHERRY (*Cornus mas. L*) USING DIFFERENT METHODS AND DETERMINATION OF BACTERICIDAL EFFECT OF THE DRIED PRODUCT ON E. COLI *(Escherichia coli)* UNDER *IN VITRO* CONDITIONS

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MSc THESIS

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THESIS APPROVAL

This thesis titled "Drying of Blueberry *(Vaccinium* spp.) and Cornelian Cherry (*Cornus mas*. L) using Different Methods, and Determination of Bactericidal Effect of the Dried Product on E. Coli (*Escherichia coli*) under *in vitro* conditions." and prepared by Mahrukh Parveez ZİA has been accepted as a **MSc** in Bursa Uludağ University Graduate School of Natural and Applied Sciences, Department of Biosystem Engineering following a unanimous vote of the jury below.

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31/07/2019

Mahrukh Parveez ZIA

ÖZET

Yüksek Lisans Tezi

YABAN MERSİNİ (*Vaccinium* spp.) VE KIZILCIĞIN(*Cornus mas* L.) FARKLI YÖNTEMLERLE KURUTULMASI VE ELDE EDİLEN KURU ÜRÜNLERİN *İN VİTRO* ORTAMDA E.*COLİ (Escherichia coli*) BAKTERİSİ ÜZERİNDE ANTİ-MİKROBİYAL ETKİSİ

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Yapılan çalışmada kızıılcık CC *(Cornus mas* L.) ve yaban mersini BB (*Vaccinium* spp.) meyveleri farklı kurutma metodları uygulanarak kurutulmuştur. Çalışma süresince kızılcık ve yaban mersini meyveleri üzerinde doğal kurutma, konvektif kurutma, mikrodalga kurutma ve konvektif–mikrodalga kurutmanın beraber kullanıldığı ısıl işlemler denenmiştir. Kurutma işlemleriyle birlikte kızılcık meyvesinin ilk nemi %72.56±0.18'den %10.27±0.13'e düşürülürken bu değer yaban mersininde %84.76±0.20'den %10.03±0.09'a indirilmiştir. Çalışma süresince en uzun kurutma süresi ve en fazla enerjinin harcandığı kurutma doğal ve konvektif (sıcak hava) kurutma olmuştur.

Çalışma, hem CC hem de BB'nin yüksek antioksidan kapasite gösterdiği ve çeşitli miktarlarda polifenolik bileşiklerden oluştuğu sonucuna varmıştır. Ayrıca, toplam antioksidan kapasiteye göre, CUPRAC en uygun yöntemdir. Çalışma sonuçlarına göre, yüksek antosyanin kapasitesi ve C vitamini açısından zengin olan bu iki meyvenin çok miktarda antosiyanin içermesine rağmen antimikrobiyal aktivite üzerinde bir etkisinin olmadığı tespit edilmiştir.

Anahtar Kelimeler: Yaban mersini, kızılcık, kurutma, antioksidan kapasitesi, antosiyanin içeriği, antimikrobiyal aktivite.

2019, viii + 80 sayfa.

ABSTRACT

MSc Thesis
DRYING OF BLUEBERRY(*Vaccinium* spp.) AND CORNELIAN CHERRY (*Cornus mas* L.) USING DIFFERENT METHODS AND DETERMINATION OF BACTERICIDAL EFFECT OF THE DRIED PRODUCT ON E.COLI (*Escherichia coli*) UNDER *IN VITRO* CONDITIONS

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In this study, different drying methods were applied to two types of fruit, that is, cornelian cherry CC (*Cornus mas* L.) and blueberry BB (*Vaccinium* spp.). During the research work, both CC and BB were exposed to natural drying, convective drying, microwave drying, and the combined microwave-convective drying. The initial moisture content of cornelian cherry (CC) at 72.56 ±0.18% was reduced down to 10.27 ± 0.13%; whereas the moisture content of blueberries (BB) initially at 84.76 ± 0.20% was reduced to 10.03 ± 0.09%. During the study, it has been found that natural and convective drying have the longest drying time and the highest values for the specific energy consumption.

The study concludes that both CC and BB show high antioxidant capacity and comprises of various amounts of polyphenolic compounds. Moreover, as per the total antioxidant capacity, CUPRAC is the most suitable method. The anthocyanin and vitamin C content for both the fruits showed high values. Even though both CC and BB contains high values of anthocyanin, no antimicrobial activity was found for both the fruit samples.

Keywords: Blueberry, cornelian cherry, drying, antioxidant capacity, anthocyanin content, antimicrobial activity

2019, viii +80 pages

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Mahrukh Parveez ZIA

31/07/2019

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SYMBOLS and ABBREVIATIONS

Symbols	Definition
*	Statistical significance higher than 5%
**	Statistical significance higher than 1%
±	Standard Error
%	Percentage value
°C	Temperature in degree Celsius
a	Redness/greenness color parameter
Abs	Absorbance
b	Yellowness/blueness color parameter
C	Chroma
h	Hour
kWh	Kilowatt-hour
L	Brightness/darkness color parameter
µmol	Micromole, unit of volume
µg	Microgram, unit of mass
mg	Milligram, unit of mass
min	Minutes, unit of time
mL	Milliliter, unit of volume
mm	Millimeter, unit of length
g	Gram, unit of mass
Kg	Kilogram, unit of mass
Ns	Statistically non-significant
UV-Vis	Ultra-voilet- Visibile Range of light
W	Watt
α	Hue angle
ε	Molar absorptivity
s	Second, unit of time
rpm	Rotation per minute
pH	Potential of Hydrogen, unit of acidity

Abbreviation	Definition
AA	Ascorbic acid
ABTS	2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid)
BB	Blueberry
CC	Cornelian cherry
Ca	Calcium
CD	Convective Drying

CDE	Cyanidin-3-O-glucoside Equivalent
CFU	Colony Forming Unit
CM	*Cornus mas*. L
CUPRAC	Cupric Reducing Antioxidant Capacity
DP	Drying Period
DPPH	2,2-diphenyl-1-picrylhydrazyl
Dw	Dry weight
EtOH	Ethanol
FCR	Folin-Ciocalteau Reagent
FD	Freeze Drying
Fe	Iron
FRAP	Ferric Reducing Antioxidant Property
Fw	Fresh Weight
GAE	Gallic Acid Equivalent
HACD	Hot-air Convective Drying
HCL	Hydrochloric Acid
HPLC	High-performance Liquid Chromatography
K	Potassium
KCL	Potassium Chloride
LC-MS	Liquid Chromatography-Mass Spectrometry
LWB	Low-bush Wild Blueberries
MeOH	Methanol
MBC	Minimal Bactericidal Concentration
Mg	Magnesium
MH	Mueller Hinton
MIC	Minimal Inhibitory Concentration
Mn	Manganese
MTC	Maximally Tolerated Concentrations
MWVD	Microwave Vacuum Drying
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
ORAC	Oxygen Radical Absorbance Capacity
TA	Total Anthocyanin
TAA	Total Ascorbic Acid
TAC	Total Antioxidant Capacity
TB%	Percentage Bio accessibility
TBP	Total Blueberry Phenolic
TEAC	Trolox Equivalent Antioxidant Capacity
TPC	Total Phenolic Capacity
VD	Vacuum Drying

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1. INTRODUCTION

Cornus mas L. (CM), commonly known as cornelian cherry (CC) of the genus *Cornus* L,belongs to the family *Cornaceae*. The genus consists of about 65 different species that are widely distributed in southern and central Europe, southwest Asia, eastern and western North America and the mountains of Central America, South America and East Africa (Dinda et al. 2016). The genus *Cornus*, mostly trees and shrubs with woody rhizomes, is commonly known as dogwood. Only some of the species namely *Cornus mas* L., *C. officinalis*, *C. controversa*, and *C. kousa*, under the genus *Cornus* contains edible fruits that are being used in different parts of Europe and Asia (Seeram et al. 2002).

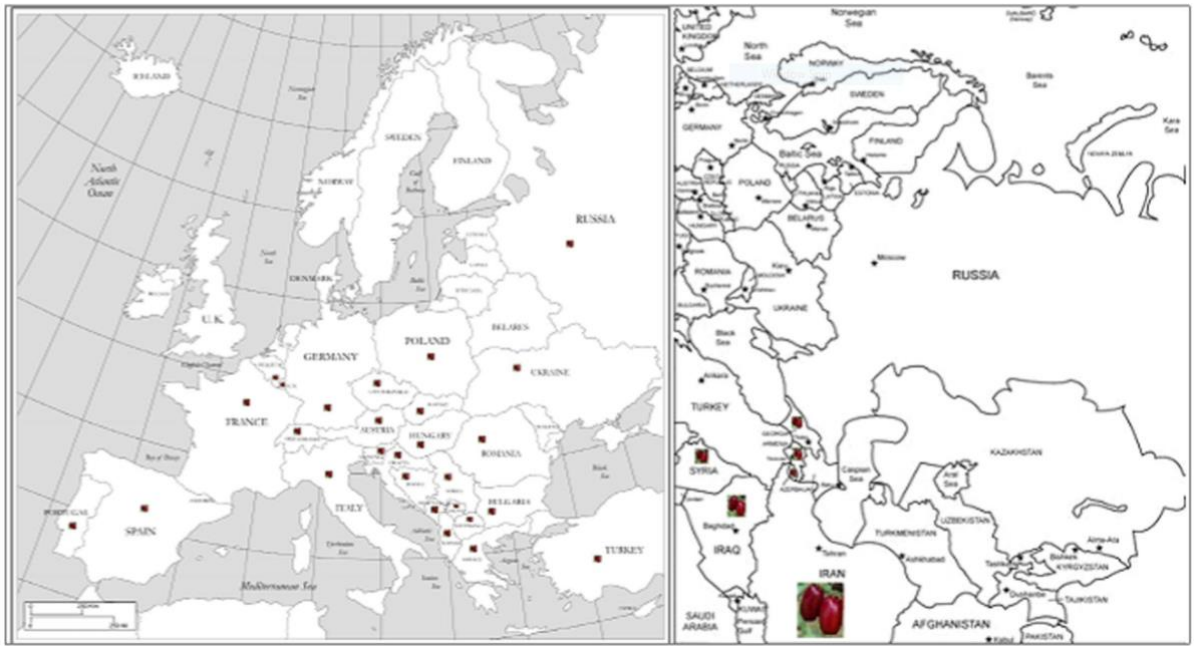


Figure 1.1. Map of Europe and West Asia that depicts the geographical distribution of cornelian cherry (Dinda et al. 2016)

The cornelian cherry tree grows up to 3-5 m and bears olive-shaped fruits which change from yellow to dark red when fully matured. The polyphenolic compounds such as anthocyanin present in the fruits as well as in the flowers and leaves of CC are the ones that give the deep red color to the fruit. The cornelian cherry fruit is consumed as fresh or dried edible fruits as well as in many other different ways as jam, marmalade, juice, compote, syrup, fruit yogurt, liquor, wine. Recently the cornelian cherry has also been

used as the flavoring agent in ice-creams, cakes, and pastries by many food manufacturers (Topdaş et al. 2017). The fruit extracts are also being used for cosmetics; in place of synthetic astringents (Cindrić et al. 2012). Traditionally, these are being used against diarrhea, diabetes, common cold, skin infections, liver diseases, and to lose weight. The ethno-medicinal use of cornelian cherry can be ascribed to the phytochemical composition of the plant. In recent years, extensive studies have been investigating the biochemical composition and nutritional importance of CC (Celep et al. 2013, Moldovan et al. 2016). Cornelian cherries possess good amounts of natural antioxidants, flavonoids, flavonols, phenolic acids and tannins, anthocyanins, iridoids, carotenoids, vitamins and carbohydrates, organic acids, fatty acids, and minerals. The total anthocyanin content (cyanidin 3*O*- galactoside being the main constituent) in CC fruits is higher compared to other fruits and vegetables. Flavonoids are mostly found in leaves of CC. Cornelian cherry is also a rich source of many essential elements, i.e. sodium (Na), potassium (K), zinc (Zn), calcium (Ca), iron (Fe), phosphorus (P), and manganese (Mn) (Cindrić et al. 2012, Gozlekci et al. 2017). Among vitamins, four vitamins, namely, riboflavin, ascorbic acid, α-tocopherol, and biotin, are found in the CC fruit, with ascorbic acid (vitamin C) present in high concentrations.

Cornelian cherry also exhibits high antioxidant activities, which makes it a potential source for natural health-promoting food and modern medicines. Many *in vitro* and *in vivo* studies have shown anthocyanins, procyanidins, and proanthocyanidins to be linked with the anti-inflammatory, antidiabetic, antiatherosclerotic actions, anticancer, and antimicrobial activities (Capanoglu et al. 2011, Cindrić et al. 2012, Dinda et al. 2016).

Blueberries, BB (*Vaccinium* spp.) are perennial flowering prostrate shrubs which belong to the genus *Vaccinium*. The various species present under this genus are *V. angustifolium* (or lowbush, wild species), *V. corymbosum* (or highbush cultivated species), *V. alaskaense, V. boreale, V. myrtillus* (also bilberry or European blueberry). Among all the known species V. *angustifolium*, and *V. corymbosum* is commonly commercially cultivated. The plant is a native of North America but is also cultivated

in countries of Europe and Southern Hemisphere, including New-Zealand, South America, and Australia (Das et al. 2017).

The plant grows from 10 cm to 4 m in height and bears pea-sized berries with a flared crown at the end — the berry changes from pale green to dark purple-blue, when ripe. Blueberries are consumed as fresh or dried edible fruits, and as puree, juice, jelly, jams, compote, frozen snack foods, as well as the flavoring agent in yogurts, pastries, cakes, and ice-creams. The consumption of BB in recent years has increased due to its nutritional importance. Blueberries have high antioxidant activities and contain various phytochemicals of dietary and pharmacological importance (Shen et al. 2014, Das et al. 2017). Blueberries are rich in phenolic acids and flavonoids, such as anthocyanin, ellagic acid, proanthocyanidin, chlorogenic acid, quercetin, and quercetin-3-galactoside (Lacombe et al. 2012, Shen et al. 2014). Vitamins like C, B complex, E, and A, and essential mineral compounds namely, selenium, zinc, iron, and manganese, along with β- carotenes, lutein, and zeaxanthin are present in significant amounts in BB (Hariram et al. 2014). Figure 1.2 shows some essential biochemical compounds present in BB.

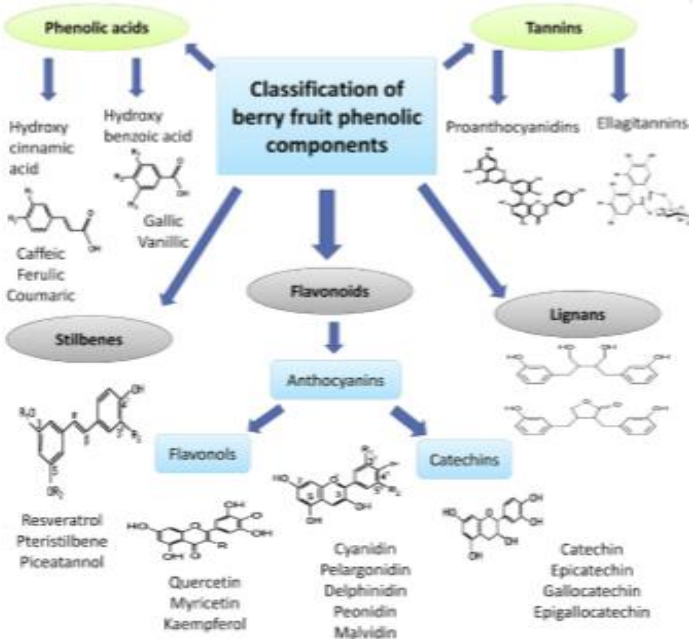


Figure 1.2. Bioactive Components in Berries (Hariram et al. 2014)

Many studies show that BB can potentially alleviate many diseases namely, cardiovascular diseases, urinary tract infections (UTIs), Alzheimer's, and cancer;

prevent macular degeneration, and reverses aging (Lacombe et al. 2012, Hariram et al. 2014). Figure.1.3 shows the biological activities of berry fruits.

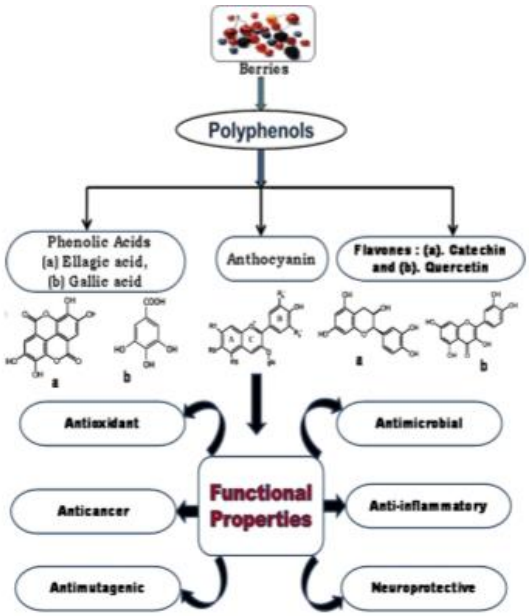


Figure.1.3. Berry phenols and flavonoids and their biological activities (Hariram et al. 2014)

Since cornelian cherry and blueberries are seasonal fruits and after harvesting does not last for longer periods. Due to this reason, there is a need for storage and to increase the shelflife of these seasonal fruits. Therefore, the oldest and the most common method for prevention of post-harvest loss of the product is drying (Yilmaz and Alibas 2017). Drying is a process of removal of moisture from the biological products to prevent it from spoilage and to increase the shelf life. The drying processes used to be carried out in open areas under the sun. Also, for aromatic and sensitive plants natural drying method (at standard room temperature at 25±1 °C; and 60-65% relative humidity) was used (Ozer 2002). Later, with the advancements in technology, many new methods were developed and used for industrial-scale drying processes. Hot-air convective drying is the most common and easy method but has many limitations, such as poor product quality, high energy consumption, loss of color, and aroma. Due to these shortcomings, novel methods such as microwave drying and combined microwave-assisted convective drying are being used. These methods are getting popular due to high product quality, short drying time, and maintaining of color, taste, and aroma.

According to the literature, combination or hybrid drying is declared to be the method of choice for drying delicate fruits like blueberries and cornelian cherry. Since these fruits are high in nutrient values, therefore such methods are needed to be applied for their commercial drying, which prevents the loss of essential nutrients and also maintains the physical properties. Many recent studies have been conducted on different methods applied to dry small fruits and berries (Vega-Gálvez et al. 2009, López et al. 2010, Yemmireddy et al. 2013, Zielinska et al. 2016, Zielinska and Michalska 2016, Zielinska and Markowski 2016, Polatoğlu and Beşe 2017, Horecki et al. 2018). In most studies, a combination of microwave and convective drying have been employed.

From the literature, it can be inferred that both cornelian cherry and blueberries are the potential superfruits which are high in bioactive components responsible for many pharmacological properties. One such property of both these fruits is their application as natural antimicrobial agents (Lacombe et al. 2012, Shen et al. 2014, Hariram et al. 2014, Dinda et al. 2016, Das et al. 2017). The most common disease-causing pathogen bacteria is *Escherichia coli. E.coli* is the common Gram-negative human pathogen bacteria which are present in the environment, food, and the gut of humans and animals. In humans, they cause diarrhea, urinary tract infections (UTIs), respiratory infections, and pneumonia. From many medical studies, it has been found that between 65%-90% of UTIs in children are due to *E. coli*. Some strains of *E.coli* such as O157: H7, produce Shiga toxin (bioterrorism agent), which destroys red blood cells.

The purpose of the study is; (1) drying of cornelian cherry (*Cornus mas* L.) and blueberry (*Vaccinium* spp.) by different methods, (2) to determine the color parameter (3) to determine the total amount of anthocyanins and vitamin C, (4) to determine the phenolic content and antioxidant capacity using ABTS, DPPH, CUPRAC methods in cornelian cherries and blueberries with highest anthocyanin and vitamin C levels and; (5) to study the antimicrobial activity of cornelian cherry and blueberry extracts on *E. coli* bacteria under *in vitro* conditions.

2. LITERATURE REVIEW

Koyuncu et al. (2007) "Drying Characteristics and Heat Energy Requirements of Cornelian Cherry Fruits (*Cornus mas* L.)," In this research work, the freshly harvested cornelian cherries were exposed to hot air drying in a parallel airflow type dryer with air velocities maintained at 0.3, 0.6, and 0.9 m s^{-1} for each temperature. The moisture content of cornelian cherry fruit was reduced from 23.3% (dry basis%) to 8%. For (70°C, 0.3 ms^{-1}), the minimum energy requirement was determined to be 11.57 kWh kg^{-1}, and for (50°C 0.9 ms^{-1}), the maximum value was 39.55 kWh kg^{-1}. Thus it can be concluded that to reduce drying energy consumption; the ideal air velocity should be at 0.3 m s^{-1} and temperature at 70°C.

Horecki et al. (2018) "Comparative Drying of Cornelian Cherries: Kinetics Modeling and Physico-chemical Properties." Convective, vacuum and freeze-drying was applied to the cornelian cherries during the study, and various physical, chemical, and biochemical attributes were also investigated. For determining the drying kinetics, eight empirical models were applied and were concluded that Midilli model is the best suitable for vacuum drying (48°C, 20 mbar, and 27 hr), and Page model was considered to be least suitable for vacuum drying of cornelian cherry. Among the different temperature applied during CD, 70°C has the shortest drying time (8 h), while 55°C has the longest drying time (20 h). The total color change for CD was in the range of 10.57 to 14.95, which is higher compared to VD and FD samples. Total phenol content (TPC) in a fresh sample of cornelian cherries was 0.52 g GAE 100 g^{-1} FW (4.72 g GAE 100 g^{-1} DW), and the FD samples showed the highest TPC values among all drying methods. Figure 2.1 illustrates the total amount of various chemical components found in dried cornelian cherry.

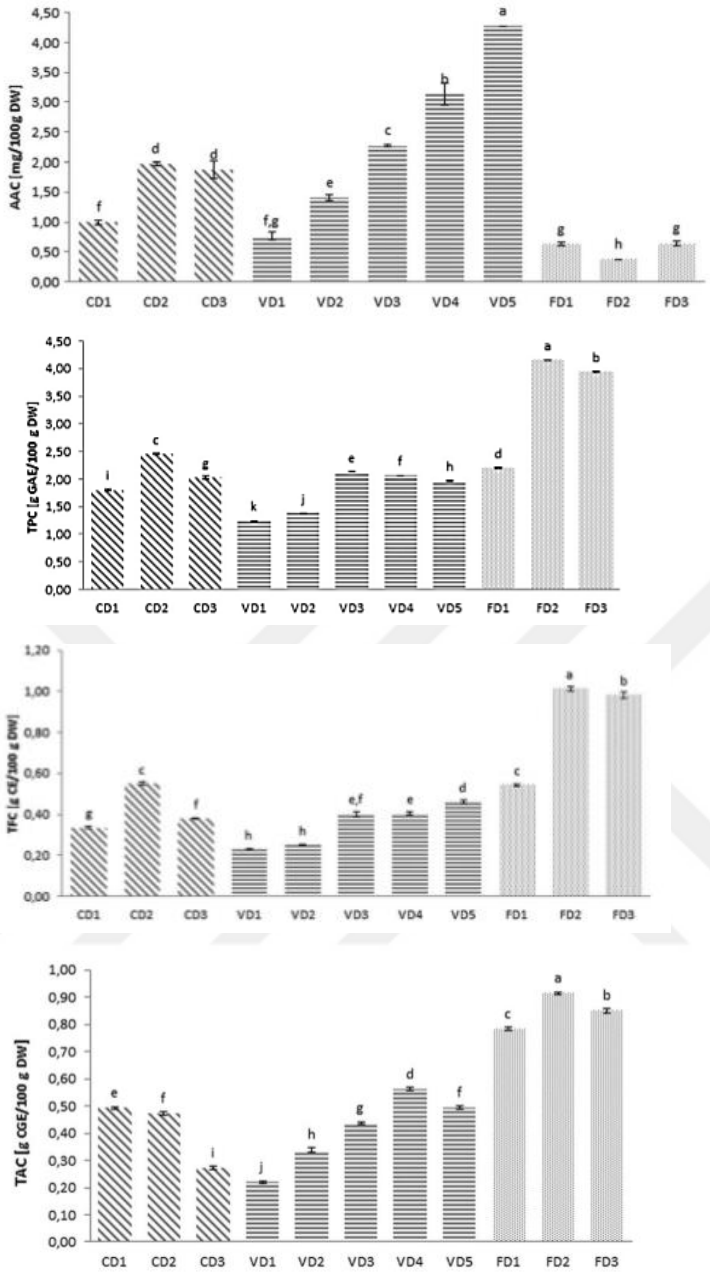


Figure 2.1. Biochemical analysis results for cornelian cherry **(a)** Ascorbic acid content of cornelian cherry for CD, VD, and FD; **(b)** TPC; **(c)** TFC, and; **(d)** TA capacity (Horeckic et al. 2018)

Moldovan et al. (2017) "Impact of Thermal Treatment on the Antioxidant Activity of Cornelian Cherries Extract." For the determination of TAC of the CC, FRAP and ABTS assay was employed. The TAC of CC extracts by ABTS, and FRAP assay was 9684.62 µM Trolox and 8982.20 µM Trolox, respectively. At 2°C cold storage, about 10% and 17% reduction was observed in the antioxidant capacity of ABTS and FRAP,

respectively while storage at 75°C showed a more significant loss (reduction up to 29%) after 10 days.

Horuz et al. (2017) “Effect of Hybrid (Microwave-Convectional) and Convectional Drying on Drying Kinetics, Total Phenols, Antioxidant Capacity, Vitamin C, Color, and Rehydration Capacity of Sour Cherries.” The cherries were dried by convective drying (CD) and microwave-convective drying or hybrid drying (HD) with power outputs at 120W, 150W, and 180W combined with hot air at 50, 60, and 70°C. The dried cherries were then evaluated for TAC, TPC, color change, and AA content. The moisture initially at 80.75%, was reduced to 25%, with the longest drying time being 2940 min for 50°C. The results show that 68.7-81.7% of TPC was lost during drying of sour cherries, along with the reduction in antioxidant capacity between 12.21-32.23%. A total of 70% vitamin C loss was observed after drying of sour cherries.

López et al. (2010) “Effect of Air Temperature on Drying Kinetics, Vitamin C, Antioxidant Activity, Total Phenolic Content, Non-enzymatic Browning and Firmness of Blueberries Variety O'Neil,” this study provides information on the effect of hot air drying between 50°C and 90°C on the antioxidant capacity, vitamin C, total phenolic content and color of blueberries. The initial moisture content was 78.5 g, crude protein 0.80 g, total lipids 0.13 g, and carbohydrates 16.2 g. During all drying temperature there was a loss in color and about 92% loss of vitamin C content as well as with the increase in the temperature total phenolic content also decreased. Besides, the antioxidant capacity was highest at 80°C and 90°C.

Grabowski et al. (2007) “Kinetics and Quality Aspects of Canadian Blueberries and Cranberries Dried by Osmo-Convective Method,” has shown that a hybrid drying technology with initial pretreatment, followed by osmotic dehydration and final convective drying of cranberries and blueberries produce high-quality end products. Furthermore, the initial anthocyanin for fresh blueberry and cranberry was reduced to 70-90 mg $100g^{-1}$ and 80 ± 10 mg $100g^{-1}$, respectively. The best taste of the dried berries was at 85℃. Due to osmotic dehydration step decolorization of the berries was found to be less than usual convective drying.

Zielinska et al. (2016) “Combined Hot Air Convective Drying and Microwave-Vacuum Drying of Blueberries (Vaccinium corymbosum L.): Drying Kinetics and Quality Characteristics.” According to this study, the blueberries exposed to hot air convective drying (HACD) and hybrid microwave-vacuum drying (MWVD) are compared with the HACD + MWVD. The quality parameters such as color, appearance, and shrinkage were evaluated for the dried blueberries. The color changes for the HACD +MWVD drying method lied between (3.08 ± 2.25 and 3.65 ± 2.28) in comparison to HACD at 60°C (8.21 ± 1.77). The HACD+MWVD achieve the best results for physico-mechanical quality parameters.

Zielinska and Markowski (2016), “The Influence of Microwave-Assisted Drying Techniques on the Rehydration Behavior of Blueberries (*Vaccinium corymbosum* L.).” This study determined the influence of different drying methods on the rehydration behavior of the blueberries. The berries were subjected to HACD, MWVD, and combined HACD+MWVD. HACD was carried out at 60°C and 80°C for 27 h and 10 h, respectively; the measurements were taken at intervals of 0.5 min. While as the berries during MWVD were subjected to 0.7 Wg^{-1} power output that lasted for 1.25 h with data recorded at every 1 min. The multi-stage HACD +MWVD at 60°C and HACD + MWVD at 80°C lasted for 7.1 h, and 3.3 h, respectively.

Vega-Gálvez et al. (2009) “Kinetic Study of Convective Drying of Blueberry Variety O'Neil (*Vaccinium corymbosum* L.).” The study was conducted at 69, 70, and 80°C with an airflow of 2.0 ± 0.2 ms^{-1}. The drying kinetics of dried blueberries was determined using different mathematical models such as Newton, Henderson-Pabis, Page, Modified Page, and Logarithmic mathematical models. The drying times for 60, 70, and 80℃ were as 1400, 800, and 500 min, respectively. Also, the results showed a falling drying rate.

Yemmireddy et al. (2013) “Effect of Drying Method on Drying Time and Physico-Chemical Properties of Dried Rabbiteye Blueberries.” During this study, drying was conducted at 85, and 107°C temperatures using various methods (Forced air drying, fluidized bed dryer, air-impingement dryer, and modified air-impingement dryer). It

was found that the drying was faster at 107°C for all drying methods. Also, various physico-chemical properties such as fat, protein, and carbohydrate content, bulk density, drying time, color, and texture were investigated.

Hassanpour et al. (2011) "Antioxidant Capacity and Phytochemical Properties of Cornelian Cherry (Cornus mas L.) Genotypes in Iran." The TPC and TAC of several CC genotypes found in East Azerbaijan were detected using the Folin-Ciocalteau and DPPH assay, respectively. The highest value for total phenol was 2695.75 mg gallic acid $100g^{-1}$ fresh weight, and the highest anthocyanin content was 422.11 mg CDE 100 g^{-1} fw. The ascorbic acid content lied between 183.25-299.5 mg $100g^{-1}$ fw.

Cetkovska et al. (2014) "Basic Nutritional Properties of Cornelian Cherry (*Cornus mas* L.) Cultivators Grown in the Czech Republic," studied the various nutritional properties such as AA, TPC, TA, and mineral contents of CC. The ascorbic acid content was found to be between 199-443 mg kg^{-1}, TPC between 2174-6143 mg kg^{-1}, TA between 61-253 mg kg^{-1} and the major elements (K, Ca, Mg, and Fe) were also found.

Dinda et al. (2016), " *Cornus mas.* L (cornelian cherry), An Important European and Asian Traditional Food and Medicine: Ethnomedicine, Phytochemistry, and Pharmacology for its Commercial Utilization in the Drug Industry", based on this review, CC fruits and leaves can be significantly used against various diseases and disorders. Some of the most common disorders such as diabetes, obesity, atherosclerosis, skin diseases, and gastrointestinal problems are reported to have successfully been treated using either the pure isolates or the plant derivates of CC. Such health benefiting activities are shown due to the presence of polyphenols and vitamins in high amounts.

Hosu et al. (2016), "Study of the Antioxidant Property Variation of Cornelian Cherry Fruits during Storage Using HPTLC and Spectrophotometric Assays," the study includes data on the variation of the TAC of CC (*Cornus mas* L.) extract during storage at room temperature. It concludes that storage of the fruit extract at room temperature for approximately three weeks does not change the nutritional health properties of these

fruits. Also, the author stated that CC could be used as a concentrated source of antioxidant compounds to develop functional foods with added health benefits.

Moldovan et al. (2016), "Antioxidant Activity of Cornelian Cherry (*Cornus mas* L.) Fruits Extract and the in vivo Evaluation of its Anti-inflammatory Effects", the results acquired in this study reveal that CCs are promising sources of efficient antioxidants and that when consumed orally shows high anti-inflammatory effects.

Kostecka et al. (2017) "Vitamin C Content of New Ecotypes of Cornelian Cherry (*Cornus mas* L.) Determined by Various Analytical Methods," The study evaluated the AA content of CC using various methods in order to determine the best and most cost-efficient analytical method. The methods applied were: Tillmans Titration Method, Iodometric Titration, Spectrophotometric method, Fluorimetric method, enzymatic method, and HPLC method. The vitamin C content varied significantly among the different ecotypes and all methods used. The results indicated that the spectrophotometric method is the ideal method of choice with the highest vitamin C concentration between 70.90–82.30 mg.100 g^{-1} and the lowest at 54.68 mg.100 g^{-1}. The HPLC method measured vitamin C concentration to be 63.1 mg·100g^{-1}, which was 4-fold higher than other analytical methods.

Kucharska et al. (2015) "Iridoids and Anthocyanins in Cornelian Cherry (Cornus mas L.) Cultivators." During this study, a qualitative and quantitative estimation of iridoids and TA was done using HPLC-DAD, LC-ESI-MS, and NMR methods. Among the flavonoids, the total iridoid ranged between 86.91 and 493.69 mg 100 g^{-1} fresh weight, and loganic acid was the main component (88-96%), followed by cornuside. Similarly, the total TAC values ranging from 5.59 to 134.57 and 341.18 mg 100g^{-1} fresh weight was obtained.

Natić et al. (2019) "Nutraceutical Properties and Phytochemical Characterization of Wild Serbian Fruits." The various wild fruits, i.e., cornelian cherry (*Cornus mas*), Hawthorn (*Crataegus monogyna*), elderberry (*Sambucus nigra*), and blackthorn (*Prunus spinosa*), were studied for their polyphenolic composition and antioxidant

capacity by *in vitro* assays. In the result, it was indicated that in blackthorn fruit 11 phenolic components could be isolated ranging between (11.24–18.70 g GAE kg^{-1} FW) with the highest antioxidant capacity (180.93–267.11 m MTE mL^{-1}).

Cosmulescu et al. (2019) "Antioxidant Capacity, Total Phenols, Total Flavonoids and Colour Component of Cornelian Cherry (*Cornus mas* L.) Wild Genotypes." For this study, many wild genotypes of cornelian cherry were examined for their bioactive components that ascribes to its potential use as a nutraceutical agent. Folin-Ciocalteau, colorimetric, and DPPH methods were applied to detect the TPC, total flavonoids, and TAC, respectively. TPC ranged between 163.69 and 359.28 mg GAE.100 g-1 FW, the highest values for total flavonoids and antioxidant capacities were at 54.26 and 64.48 mg QE 100 g^{-1} FW, and 2.39 and 2.71 mmol Trolox 100 g^{-1} FW, respectively.

Gunduz et al. (2013) "Antioxidant, Physical and Chemical Characteristics of Cornelian Cherry Fruits (*Cornus mas* L.) at Different Stages of Ripeness." At four ripening stages (light yellow, blush, light red, and dark red) of cornelian cherry, a thorough examination was conducted to demonstrate the changes in the physical and chemical characteristics. An overall increase in fruit size, weight, and sugar/acid ratio was observed, while total titratable acidity decreased. The color changed from yellow to dark red as the fruit matured and anthocyanins start accumulating. TPC and TEAC averages at light yellow stage were (8033 μg GAE g^{-1} fresh weight (fw) and 55.0 μmol Trolox g^{-1} fw) and reduced at the dark red stages (4162 μg GAE g^{-1} fw and 7.8 μmol Trolox g^{-1} fw). Tannin content decreased (from 0.45 to 0.19%) during light yellow to dark red stages.

Biaggi et al. (2018) "*Cornus mas* (L.) Fruit as a Potential Source of Natural Health-Promoting Compounds: Physico-Chemical Characterisation of Bioactive Components," named research study puts forward the nutraceutical properties of cornelian cherry and demonstrates the various physical and chemical attributes of the bioactive components such as the total phenolic content (TPC; 196.68 ±24.68 mg GAE $100g^{-1}$ fresh weight), total anthocyanidin content (TAC; 134.71±7.10 mg C3G $100g^{-1}$ fresh weight), and antioxidant capacity (20.41±0.50 mmol Fe^{2+} kg^{-1}). The phytochemical analysis of cornelian cherry fruits was carried out by HPLC-DAD. The Figure illustrates the

phytochemical composition of *Cornus mas* L. isolated and quantified by HPLC-DAD method.

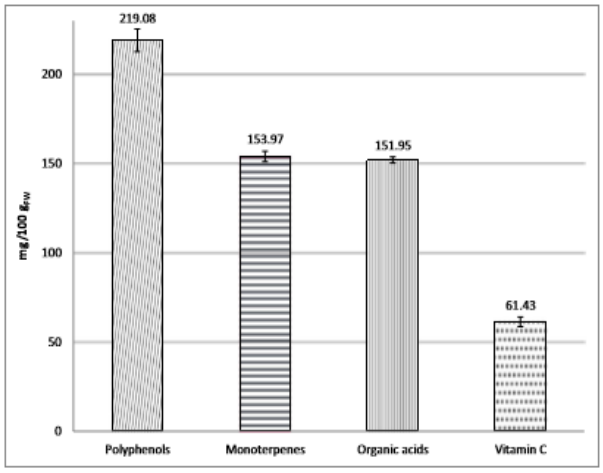


Figure 2.2. Phytocomplex representation of cornelian cherry.
Biaggi et al. (2018)

Kraujalyte et al. (2015) "Antioxidant Properties, Phenolic Composition and Potentiometric Sensor Array Evaluation of Commercial and New Blueberry (*Vaccinium corymbosum*) and Bog Blueberry (*Vaccinium uliginosum*) Genotypes." The study investigated the antioxidant properties from the juices of blueberry and wild bog blueberry. In order to estimate the antioxidant activity, ABTS, a radical scavenging assay, FRAP, ORAC were used; also, total phenolic content (TPC), and total anthocyanin content (TA) were evaluated. The results of the assays are as follows: TPC ranged from 0.85-2.81 mg GAE mL^{-1}, FRAP, and ORAC as 3.07-17.8, and 4.21-45.68 µmol Trolox g^{-1}, respectively. The study concluded that the BB and blog blueberry demonstrated stronger antioxidant and total anthocyanin capacity than other studied genotypes.

Hariram et al. (2014) "Edible Berries: Bioactive Components and Their Effect on Human Health." This review study has put forward the fact that in recent years through several *in vitro* and *in vivo studies,* it has been established that the biochemical components present in berries have many health benefits. These positive health effects are ascribed to the presence of phenolic acids, flavonoids, tannins, and multi-vitamins.

These bioactive compounds have antioxidant, anticarcinogenic, bactericidal, anti-inflammatory, and neuroprotective properties which have led in the development of alternatives for prevention of various diseases and disorders.

Kalt et al. (1999 a) "Antioxidant Capacity, Vitamin C, Phenolics, and Anthocyanins after Fresh Storage of Small Fruits." A comparative study comprising of four different types of berries- fresh strawberries, raspberries, wild blueberries, and newly bred blueberries was conducted in reference to the TAC, AA, phenolics, and TA stored between 0°C and 30°C for up to 8 days. This study was done in order to see the effect of storage temperature on the whole fruit biochemical properties (Table 2.1). The study concluded that the antioxidant capacity of blueberry is 3-fold higher than both raspberry and strawberry, whereas, at temperatures greater than 0°C the antioxidant capacity, total phenolic content and anthocyanin of both raspberries and strawberries shows an increase. Ascorbate has low to no change during the 8 days storage and contributes only about 0.4-9.4% to the TAC of the fruit.

Table 2.1. TPC, TA content, total AA content, and TAC ($ORAC_{ROO}$ •) of four fruit species at harvest[a] (Kalt et al. 1999 a)

Fruit	TPC µmol of gallic acid/ g FW	TA µmol of Mal-3-glu/g FW	AA µmol/gFW	TAC µmol of trolox eq/g FW
Strawberry	5.08 (0.438)	0.155 (0.028)	1.96 (0.147)	20.6 (2.33)
Raspberry	7.10 (0.188)	0.084 (0.053)	1.23 (0.066)	21.4 (2.24)
Highbush blueberry	22.7 (0.804)	2.67 (0.097)	0.489 (0.031)	60.1 (2.81)
Lowbush blueberry	27.7 (1.09)	4.35 (0.160)	0.358 (0.014)	64.4 (3.68)
F probability	<0.001	<0.001	<0.001	<0.001
S.E.	0.566	0.0359	0.0281	2.25

[a] Standard error values are given in parentheses. For each fruit n = 4
TPC, total phenolic content; TA, total anthocyanin; AA ascorbic acid; TAC, total antioxidant capacity

Kalt et al. (1999 b) "Anthocyanin Content and Profile Within and Among Blueberry Species." This study illustrated the inter- and- intraspecies variability among four types of blueberries for TA content. The study says that *V. myrtillus* L. variety, also known as

bilberry or European blueberry has the highest anthocyanin content followed by *V. myrtilloides* L. with about 43% of the TA content compared to fresh bilberry. Besides, all the wild genotypes have about 60% anthocyanin. The study also concluded that the variation in the TA content does not affect the TAC of the fruits.

Das et al. (2017) "Potential of Berry Extracts to Control Foodborne Pathogens." This review study concentrates on the potential use of berry extracts as antibacterial agents to prevent the growth and reproduction of harmful bacteria within the food products, therefore to manage serious health problems related to the foodborne diseases. The use of fruit or plant extracts as an inhibitory agent is essential also because of the increasing antibiotic-resistant bacterial population, which has led to the need for developing novel treatments methods. This study reports the mode of action of these fruit extracts against the bacterial cell. It has found that the extracts from the cranberries (proanthocyanidins) demonstrate anti-adhesive characteristics, which inhibits bacterial growth. Also, blueberries and strawberries are reported to decrease cell auto-aggregation, motility, and affect cellular hydrophobicity. Furthermore, the cranberry extracts have shown strong bactericidal activity against Gram-positive bacteria such as *Staphylococcus* spp., while blueberry is said to show better activity against Gram-negative bacteria, especially *S. Enteritidis* and Shiga toxin-producing *E.coli* O157: H7. Similarly, strawberries have better activity against Gram-negative bacterial strains like *S. enterica*, and *E.coli* CM 871 (MIC=1 mg mL^{-1}).

Caillet et al. (2012) "Antimicrobial Effect of Fractions From Cranberry Products on the Growth of Seven Pathogenic Bacteria." The research was done to verify the antibacterial activity of cranberry juice and pomace extracts against seven different bacterial strains, including Gram-positive and Gram-negative bacteria. The minimum inhibitory concentration (MIC) and maximally tolerated concentrations (MTC) determined the antimicrobial activity of the cranberry products. The results proved that all the bacterial strains showed selective inhibition for the phenolic extracts. L. *monocytogenes* were most susceptible to the treatment; whereas, *E.coli* O157: H7 was least sensitive to the phenolic compounds.

Tural and Koca (2008) "Physico-Chemical and Antioxidant Properties of Cornelian Cherry Fruits (Cornus mas L.) Grown in Turkey." The present research was pursued to assess the physical and chemical properties of cornelian cherry. Physical attributes such as weight, size, color, moisture content, and dry matter, as well as chemical attributes viz total acidity, sugar, ascorbic acid, total phenols, and total anthocyanins, were calculated. The results are given in Table 2.2 below.

Table 2.2. Physical and chemical properties of cornelian cherry fruits

Parameters	Range	Means±S.D.
L	10.82–19.69	14.4±2.39
+a	6.25–15.59	10.49±2.64
+b	4.99±0.83	3.46–6.64
Ascorbic acid (mg g^{-1})	0.16–0.88	0.532 ±12.88
Total phenolics (mg g^{-1})	2.81–5.79	4.37±835.76
Total anthocyanin (mg g^{-1})	1.12–2.92	1.97±588.48
FRAP (mmol g^{-1})	16.21–94.43	53.92±20.12
EC50 (mg mL^{-1})	0.29–0.69	0.52±0.13

±SD, Standard deviation

Fawole et al. (2012) "Antibacterial, Antioxidant and Tyrosinase-Inhibition Activities of Pomegranate Fruit Peel Methanolic Extract," named study evaluated the antibacterial, and antioxidant activities of pomegranate peel, using *in vitro* assays. Two Gram-positive strains (*B. subtilis* and *S. aureus*) and two Gram-negative strains (*E. coli* and *K. pneumonia*) were tested using the microdilution method. The results showed that the methanolic peel extracts have a strong, broad-spectrum antimicrobial activity. It was concluded that the pomegranate peels have a very high amount of phenolic compounds which ranges between 179.3 and 295.5 mg. g^{-1} dry extract, and ellagic acid present in

significant abundance. Also, TAC was approximately 83.56% at the highest concentration (1000 µg mL^{-1})

Michalska et al. (2017) "Effect of Different Drying Techniques on Physical Properties, Total Polyphenols and Antioxidant Capacity of Blackcurrant Pomace Powder," named study examined blackcurrant pomace powder to see the effect of different drying methods on it. The drying was carried out as freeze-drying, convective drying, microwave vacuum drying, and combined convective-microwave-vacuum drying. The various physical, as well as chemical attributes, were analyzed during the study. The analysis reported, that regardless of the method applied for drying, both TPC and TAC of the blackcurrant pomace powder were reduced significantly and at 90°C CD was 32% lesser than at 50°C. For color measurements, the lowest value for *L* was at 120W (MWVD), and the highest value for *a* and chroma *C* was for FD. The shortest drying time was observed at 480W power and the longest at 50°C.

Turker et al. (2012) "Antibacterial and Antitumor Activities of Some Wild Fruits Grown in Turkey." The study was conducted over eight different wild fruits, including cornelian cherry grown in Turkey. Two bioassays, one antibacterial, and other antitumor were performed to evaluate the bioactivity. The best results for antibacterial activity were shown by the hot ethanol extracts of hawthorn, firethorn and wayfaring tree against *S. aureus, S. epidermidis*, and *S. pyogenes.* On the other hand, strong antitumor activity was recorded from the cold aqueous extracts of dewberry with 100% inhibition, followed by wayfaring tree (90.5%), hawthorn fruit (85.7%), and lam fruit (71.4%).

Agourram et al. (2013) "Phenolic Content, Antioxidant Potential, and Antimicrobial Activities of Fruit and Vegetable By-product Extracts." This research contains data on biologically active compounds of 13 different fruits and vegetables, which can be potentially used as the natural additives and natural antibacterial agents. Out of all the products tested for the total phenols and antioxidant capacity, pomegranate peels, and hazelnut skins had the highest values for both TPC and TAC. The antimicrobial activity of the product extracts was carried out against 13 Gram-positive and Gram-negative bacterial strains Among all the bacterial strains tested for antibacterial activity, it was

shown that *Staphylococcus aureus* and *Pseudomonas fluorescens* are most susceptible to pomegranate and apple peels extracts.

Antolak et al. (2017) "Phenolic Compounds Contained in Little-known Wild Fruits as Antiadhesive Agents Against the Beverage-Spoiling Bacteria Asaia spp." A study was conducted to evaluate the TAC and TPC from the juice of three kinds of fruits; cornelian cherry, elderberry, and lingonberry, and their antibacterial activity were tested against *Asaia lannensis* and *Asaia bogorensis*. DPPH and FRAP assays determined the TAC, as well as the chemical composition of the fruit juices, was evaluated using HPLC, and liquid chromatography-mass spectrometry (LC-MS). Total antioxidant capacity values of the fruit juices ranged from 0.042±0.001 (cornelian cherry) to 0.021±0.001 $g.mL^{-1}$ (elderberry), whereas, the TPC values lied between 8.02±0.027 (elderberry) to 2.33±0.013 mg mL^{-1} (cornelian cherry).

Krisch et al. (2008) "Effect of Fruit Juices and Pomace Extracts on the Growth of Gram-positive and Gram-negative Bacteria," named study the antibacterial activity of 21 different kinds of fruits was investigated against an array of Gram-positive and Gram-negative bacterial strains using microdilution method. The results show that the blackcurrant, cornelian cherry, and the European rowan had the best inhibition capacity, while sweet cherry, hawthorn, and elderberry showed weak or no bactericidal activity.

Barak et al. (2019) "Influence of In Vitro Human Digestion on the Bioavailability of Phenolic Content and Antioxidant Activity of *Viburnum opulus* L. (European cranberry) Fruit Extracts." The study was designed based on the TAC and polyphenolic profile of cranberry before and after *in vitro* gastrointestinal human digestion. High-performance thin-layer liquid chromatography (HPTLC) method was applied to isolate and quantify the polyphenols. Various other assays like DPPH, FRAP, and CUPRAC for two extraction medium (methanolic and aqueous), were employed to detect the TAC values of the fruits. The results concluded that bioavailability of methanolic extracts has higher values than that of the aqueous extracts.

Kalifa et al. (2015) “Antimicrobial Effect of Blueberry, Raspberry, and Strawberry Aqueous Extracts and Their Effects on Virulence Gene Expression in *Vibrio cholerae*.” Against 13 pathogenic strains, the antimicrobial activity of aqueous extracts of blueberry, raspberry, and strawberry was estimated. The MICs/MBCs values showed that all bacterial strains were selectively inhibited, while blueberry was the best inhibitor. It was also concluded that all three fruit extracts exhibit repression of *tcpA* gene transcription.

Capanoglu et al. (2011) “Procyanidins in fruit from Sour cherry (*Prunus cerasus*) differ strongly in chain length from those in Laurel cherry (*Prunus lauracerasus*) and Cornelian cherry (*Cornus mas*).” The phytochemical composition and TAC of three kinds of cherries; sour cherry, cornelian cherry, and laurel cherry was studied. It has been found that laurel cherries possessed higher amounts of long-chain proanthocyanidins up to 1 g.100 g^{-1} dw, whereas, for cornelian cherry, the amount was 25 times lower. Besides, small-chain proanthocyanidins were found in sour cherry with 0.3g.100 g^{-1} dw.

Shen et al. (2014) “Antimicrobial Effect of Blueberry (*Vaccinium corymbosum* L.) Extracts Against the Growth of *Listeria monocytogenes* and *Salmonella Enteritidis*.” The work undertaken during this study gives data on the antimicrobial activity of blueberry extracts against the foodborne pathogens. The TPC of the extracts was measured using the Folin-Ciocalteau method, and the separation of different types of phenols was done by HPLC method. The TPC ranged from (3.10-5.05 mg GAE. g^{-1} fw). It suggested that the phenolic compounds at 112.5-900 mg. mL^{-1} concentration showed an inhibitory effect against *L. monocytogenes* and *S. Enteriditis*. The MBC/MIC values also showed that *L.monocytogenes* were more sensitive to the treatment than *S. Enteriditis.* Besides the phenolic compounds, the pH of the fruit extract also has the antimicrobial activity. At a pH of 3.4, the initial viable cell count at 4.7 ±0.1 was reduced to 2.3 ±0.2 log CFU.mL^{-1}

Lacombe et al. (2012) “The Antimicrobial Properties of the Low Bush Blueberry (*Vaccinium angustifolium*) Fractional Components Against Foodborne Pathogens and

the Conservation of Probiotic *Lactobacillus rhamnosus*." Under this article, the extracts of blueberry are tested for antimicrobial activity against many bacterial strains, and one of them being *E.coli*. The agar diffusion method is applied for the initial screening of each fraction, followed by minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) determination by two-fold dilution and viable cell count, taken at initial and the final hour, methods. The anthocyanins + proanthocyanidins fraction demonstrated lowest MICs/MBCs, and *L. monocytogenes* and *L. rhamnosus* are found to be most susceptible and the least to the fraction treatment respectively.

Lacombe et al. (2013) "Phytochemicals in Lowbush Wild Blueberry Inactivate Escherichia coli O157: H7 by Damaging Its Cell Membrane." According to the article, the antimicrobial activity of the polyphenolic phytochemical compounds of lowbush wild BB against E.coli O157: H7 strain was studied. The total blueberry phenolics (TBP) extracted by 80% v/v methanol was further fractioned as monomeric phenolic acids (MPA), proanthocyanidins + anthocyanins (P&A), anthocyanins, and proanthocyanidins. In the phenolic fractions, viable cell counts method was applied for *E.coli* population estimation. To determine the plasma membrane permeability of E. coli O157: H7 LIVE/DEAD viability assay was used, and the impairment occurred within the cell membranes was seen by using transmission electron microscopy (TEM). The anthocyanin fraction produced the highest degree of permeability in the cell membrane as well as the lowest recovery of the bacterial strain. Figure 2.3 and 2.4 show the results for antimoicrobial activity of the blueberries against *E. coli*.

Sun et al. (2018) "Antibacterial Effect and Mechanism of Anthocyanin-rich Chinese Wild Blueberry Extract on Various Foodborne Pathogens." Under the article, the author investigates the antibacterial effect of anthocyanin, a phytochemical compound, found in high concentrations in wild berries. The anthocyanin extracts from Chinese wild blueberries were studied for the inhibition of various pathogenic bacteria. The pathogens are treated with the extract for 2 h, followed by the evaluation of the damage caused to the cell membrane. The results show that *V. parahaemolyticus* is highly susceptible to the treatment with the lowest MIC/MBC values. Furthermore, the

production rate of formazan produced by the pathogens decreased between 55% and 79%, inferring inhibition of growth and reproduction of the bacteria.

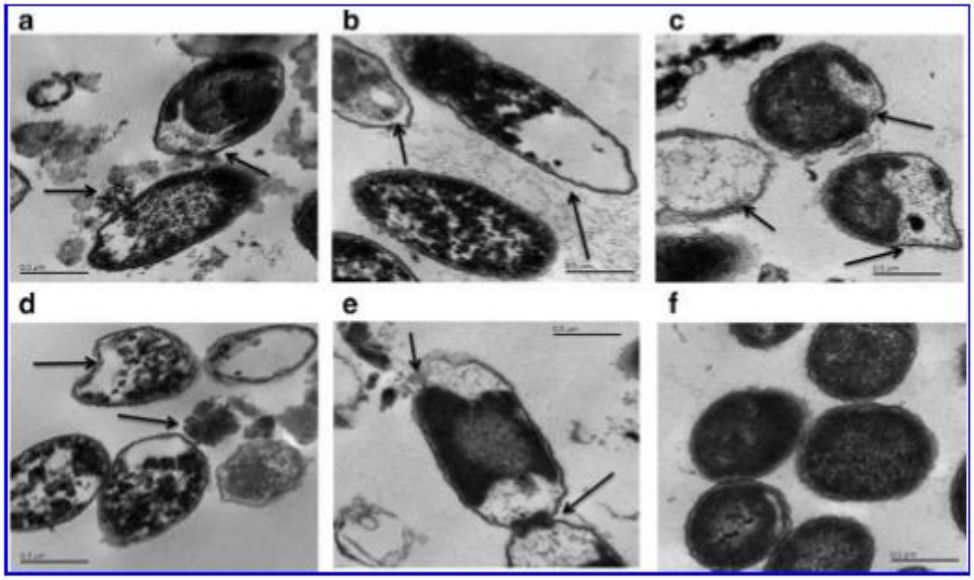
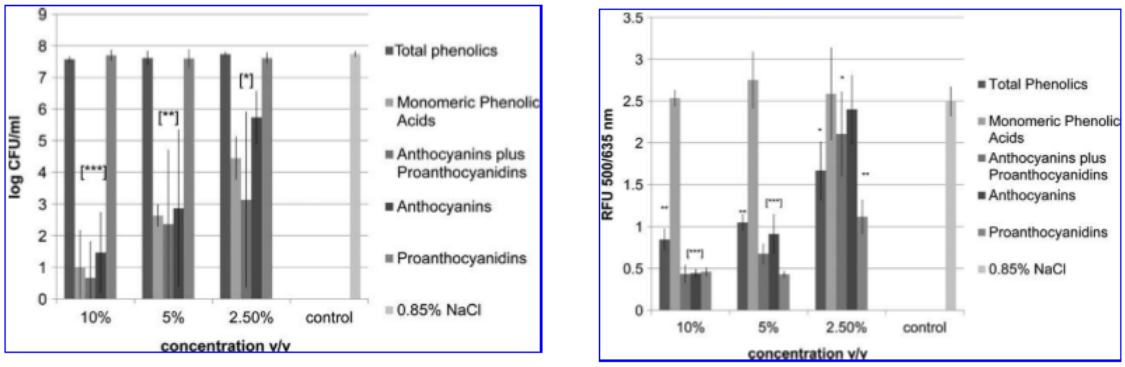


Figure 2.3. Micrographs of E.coli O157:H7 at 46,000x treated with 5%v/v of blueberry fractions: (a) total phenolics, (b) monomeric phenolic acids, (c) anthocyanins plus proanthocyanidins, (d) anthocyanins, (e) proanthocyanidins, and (f) control. Arrow indicates areas of significant damage (Lacombe et al. 2013).



(a) (b)

Figure 2.4. (a) Inactivation of *E.coli* by LWB phenolic fractions at 2.5, 2, and 10% in 0.85% w/v NaCl.

(b) The effect LWB phenolic fractions on the membrane permeability of *E.coli*. (Lacombe et al. 2013

3. MATERIAL AND METHOD

3.1. Materials

The material section has been broadly categorized into three main sub-headings as follows- Fresh fruits, Chemical and Reagents, and Equipment and Devices.

3.1.1. Fresh Fruits

Cornelian Cherry (CC)

Cornelian cherry (*Cornus mas* L.) was bought from the fruit growers in Orhaneli district of Bursa, Turkey. The fruits were cleaned, handpicked, and then stored at 4°C until used.

Figure 3.1. Fresh Cornelian Cherry

Blueberry (BB)

Blueberries (*Vaccinium* spp.*)* were provided by a food company named Ideal Tarim from Turkey. The fruits were stored at 4°C until used.

Figure 3.2. Fresh Blueberries

3.1.2. Apparatus and Analytical Instruments

Digital Laboratory Weighing Scales and Vortex

During the experimental study, a laboratory scale (Radwag, PS 4500 R2, Poland) with 0.01g sensitivity, the cornelian cherries, and blueberries were weighed. Also, for the chemicals and reagents more sensitive balance (Metler-Toledo, ME-203, Switzerland) with (d=0.0001g) and 210 g total capacity were used. Figure 3.3 (a,b) shows the different types of balance used. Alongside the balance, for the mixing of the chemical reagents, an electronic vortex (Velp Scientifica, Italy) was used. Figure 3.3 (c) shows the picture of an electronic vortex.

(a) (b) (c)

Figure 3.3 (a,b) Laboratory Scales; **(c)** Electronic Vortex Mixer.

Centrifuge and Micropipettes

During the biochemical analysis, the fruit extracts were to be separated from the extraction solution. This was done using benchtop centrifuges (Sigma 3K30, UK) with 50 ml tube capacity, and (Nuve NF 200, Turkey) with 15 ml tube capacity. Fig 3.4 (a) shows the centrifuge used. For measuring small volumes of solutions micropipettes (ISOLAB laborgeräte, GmbH) ranging between (2 µl- 10 ml) were used. Figure 3.4 (b) depicts the various types of micropipettes been used.

(a) (b)

Figure 3.4. (a) Centrifuge and **(b)** Micropipettes

Waterbath and pH meter

For the preparation of the homogenizing chemical solution, maintained at certain temperatures, a shaking water bath (Nuve ST 30) was used. During the biochemical analysis, many buffer solutions were prepared and to determine the required pH of these solutions, a digital pH meter (Mettler Toledo, Turkey) with a magnetic plate to maintain the temperature of the buffer solutions was used. The pH meter was callibrated using calibration solution before every reading. Figure 3.5 shows the water bath and pH meter used during the process.

(a) (b)

Figure 3.5. **(a)** Water bath and **(b)** pH meter

Glass Apparatus and Mortar-Pestle

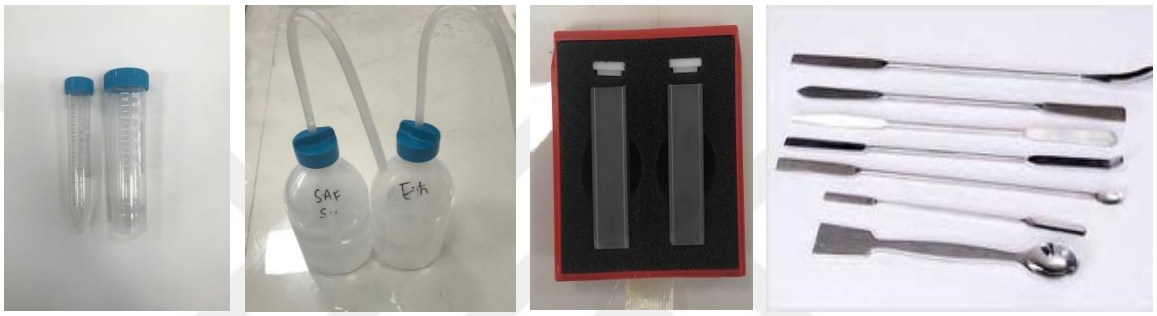
During the experimental study, various glassware of different volumes and sizes such as beakers, volumetric flasks, conical flasks, and measuring cylinders were used. In order to homogenize the dried cornelian cherry and blueberries into a fine dry powder, porcelain mortar and pestle were used. Figure 3.6 shows the different types of lab glassware and mortar-pestle.

(a) (b)

Figure 3.6 (a) Glass Apparatus, and **(b)** Mortar-Pestle

Test tubes, Cuvettes, Spatulas, and Wash bottles

To perform the chemical analysis test tubes of two different volumes, 15 ml and 50 ml (ISOLAB, Turkey) were used. Also, to acquire the desired amount of chemicals during weighing, a range of spatulas (ISOLAB, Turkey) were used. For performing, spectrophotometric analysis quartz cuvettes were used. To wash the test tubes and cuvettes during the experiments, 500 ml wash bottles were also used. Figure 3.7 shows a picture of the apparatus used.



(a) (b) (c) (d)

Figure 3.7 (a) Test tubes, **(b)** Wash bottles, **(c)** Quartz cuvette, and **(d)** Spatulas

UV-Vis Spectrophotometer

The biochemical analysis of cornelian cherries and blueberries was conducted using the UV-Vis spectrophotometer (Spectrum Instruments SP-UV 300SRB, Germany). The spectrophotometric analysis were operated within the Vis- light range of 400-750 nm. Figure 3.8 shows the spectrophotometer used.

Figure 3.8. UV-Vis Spectrophotometer

Convective Hot-air Oven and Microwave Oven

For the drying of fresh cornelian cherry (CC) and blueberries (BB) using the convective hot-air drying method, a multi-tray industrial type hot-air oven (INOKSAN FBE 006, Turkey). The convection oven consists of 6 trays with each tray dimensions (400x 600 mm). To conduct the drying process using microwave drying method (MWD) and combination microwave-convectional drying (MWCD), a multifunctional microwave oven (Electrolux EVY7800AAX, USA), with technical specifications as follows: 230 ± 10 V~, 50 Hz and 3000 W was used. The oven works between 30°C and 230°C temperatures; whereas for microwave drying the power outputs ranges between 100-1000W, and for combination drying the maimum power combination is at 600W. The area of the oven is 800x430x210 mm, and a Teflon tray with dimensions 410x320 mm was used. Figure 3.9 shows the types of oven been used during the study.

(a) (b)

Figure 3.9 (a) Convective hot-air oven, and **(b)** Microwave oven

Colorimeter and Laminar Flow

To determine the color parameters of both the fruits, a photo-electronic colorimeter Minolta CR 10 (Konica-Minolta, Osaka, Japan) was used. The chemicals used for the biological analysis are volatile in nature. Therefore, all the chemical stock solutions were prepared under laminar flow (Hedlab, Turkey) in order to remove the fumes of these volatile chemicals. Figure 3.10 shows the colorimeter and laminar flow.

(a) (b)

Figure 3.10 (a) Colorimeter and **(b)** Laminar flow

3.1.3. Chemicals and Reagents

Methanol (MeOH), Ethanol (EtOH), and Doubled Distilled Water (dd H_2O)

The extraction of dried cornelian cherry (CC) and blueberries (BB) was carried out using 99.7% pure methanol and ethanol (Sigma-Aldrich) with double-distilled water (ddH_2O) using a Milli-Q system (Millipore, Bedford, MA, USA).

Chemicals used for total phenolic and antioxidant capacity

The various chemicals used for phenol estimation in dried cornelian cherry and blueberries are as follows- analytical grade Gallic acid 91215 (Fluka, St. Louis, MO, USA), Folin-Ciocalteu reagent (FCR), Trolox ((±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) (238813), Neocuproine (2,9-dimethyl-1,10-phenanthroline) (N1501), 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) (D9132), ABTS (2,2´-azinobis (3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt) (A1888) were all purchased from (Aldrich, St. Loius, MO, USA).

Chemical used for anthocyanin and vitamin C

For anthocyanin analysis, all the chemical used were of analytical grade such as-potassium chloride (KCL), sodium acetate ($CH_3COONa.\ 3H_2O$), HCL (Hydrochloric acid 37% purity) all purchased from (Merck, Germany). For vitamin C analysis, good grade analytical chemicals and reagents were being used. L-Ascorbic acid, oxalic acid, glacial acetic acid, metaphosphoric acid, and 2,6-dicholorophenolindophenol were are purchased from Merck, Germany.

3.2. Methods

3.2.1. Sample preparation

The fresh cornelian cherry and blueberries were handpicked, cleaned, and washed to remove any dirt and spoiled fruit. The fruits were then laid on trays until the excess water was drained off.

3.2.2. Drying process

The prepared fresh fruit samples of both cornelian cherry and blueberries were separated into sampler units (50 ± 0.5 g each unit). All the drying process was carried out in triplicates.

Natural drying (ND)

During the natural drying method, the fruit samples were kept in a dark room with controlled temperature 25±1°C, and the relative humidity at 60±5%. The initial weight and moisture content were noted on the first day; later, at the interval of 6 hours was recorded to estimate the reduction in the weight of the samples.

Convective hot-air Drying (CD)

The small 50 ± 0.5 g units of fruit sample were laid on a Teflon tray in a convective oven and were exposed to temperatures at 50, 70, and 90°C, with $1ms^{-1}$ velocity. The experiment was repeated three times for all the three temperature containing both cornelian cherry and blueberries. For every trial, the weight of the samples was measured at an interval of 5 min each.

Microwave Drying (MWD)

The fresh cornelian cherry and blueberry samples with an initial weight of 50±0.25 g were put inside a multifunctional programmable microwave oven with a power output range between 100W-1000W. The samples were exposed to microwave power at 100, 300, and 500 W and were weighed at an interval of 1 min each. The process took place in three replicas for all power outputs, including both the fruit samples.

Combined Microwave and Convective Drying (MWCD)

A combination of microwave and hot-air drying was applied using a combination oven at temperatures 90°C, 70°C, and 50°C and with 100W, 300W, and 500W. For each microwave power, all three temperature combinations such as (100W-50°C, 100W-70°C, 100W-90°C, 300W-50°C, 300W-70°C, 300W-90°C, 500W-50°C, 500W-70°C, and 500W-90°C) were applied making a total of 9 treatment sets for both the fruit samples. The samples were weighed at every 30 seconds interval. The readings were taken as the mean of triplicate trials. The initial weight for all the samples was at 50±0.5 g.

Color Parameters

The color parameters of both cornelian cherry and blueberries were measured using a photoelectric colorimeter, calibrated with standard white tile. For every drying treatment, ten different readings were used to determine the color parameters of each

fruit samples. *L* is the brightness coordinate whose values range between 0 and 100 (0 for black, and 100 for white). Also, coordinate "*a*" denotes red for positive values and green for negative values. Similarly, color-coordinate "*b*" shows yellow for positive values and blue for negative values. The chroma (C) and hue angle (α°) values were estimated directly from the colorimeter.

3.2.3 Biochemical analysis of cornelian cherry and blueberry

Sample preparation

The fresh and dried samples of cornelian cherry and blueberries were ground using mortar and pestle. For each trial, 1 g of these powder samples were mixed with 10 mL conc. methanol/water/ HCL (90:10:1 v/v) mixture in a 50 ml test tube and homogenized in a shaker water bath at 20°C for 2 h, centrifuged at 3500 rpm for 10 min at 4°C; later, the supernatant was filtered into new 15 ml test tubes and stored at -4°C until used for biochemical testing (Vitali et al. 2009). The solid residue left in 50 ml test tube was again homogenized with a mixture of conc. H_2SO_4/ methanol (1/10 v/v) using a shaker water bath at 85°C for 20 h. During this step, the fruit samples are hydrolyzed in H_2SO_4/ methanol mixture. The tube caps are covered airtight to prevent evaporation of the solution. After 20 h shaking, the samples were allowed to reach the room temperature, and the volume was again brought up to 20 mL with the same solvent mixture. After centrifuging the sample at 3500 rpm for 10 min at 4°C temperature, the supernatant was then separated and kept at -4°C until used.

Similarly, for in vitro digestion extraction method, bio-accessible extracts were prepared by treating the fruit samples with gastrointestinal enzymes. In a 50 ml tube, 1 g of powder sample was mixed with 20 mL water and 1 mL pepsin solution (2 g of pepsin dissolved in HCL/water; 1:99 mL v/v solution). The pH of the sample was maintained at 2 to mimic the acidic conditions of the stomach. The samples were put in a shaker water bath for 1 hr at 37°C. After 1 hour shaking, the pH of the samples was brought to 7.2 by adding bile/pancreatin buffer solution to each sample, thus changing the acidic conditions to basic. After the addition of the bile/pancreatin buffer solution, the samples

were again put in the water bath for 2.5 h at 37°C. Later, the samples were centrifuged at 3500 rpm for 10 min at 4°C. The aliquots were stored at -4°C until used.

3.2.4.Total Phenolic Content (TPC)

TPC of both cornelian cherry and blueberry samples were estimated using a modified Folin-Ciocalteu colorimetric method (Apak et al. 2008). A solution was prepared using gallic acid (GA) mixed with 10-fold diluted FCR and sodium bicarbonate solution and are left for 30 min incubation in the dark. Later measurements were taken at 750 nm against blank for the calibration of the standard curve.

Similarly, the extracted, hydrolyzed, and bioaccessible aliquots of both cornelian cherry and blueberries were prepared using a mixture Folin-Ciocalteu reagent along with sodium bicarbonate solution and then following the previous steps as for calibration curve incubated in the dark for 30 min at room temperature. Later, the absorbance of each aliquot for both the fruits was measured at 750 nm using a spectrophotometer. The results were expressed as mg gallic acid equivalent (GAE) g^{-1}. The data presented was the average of triplicate analysis.

3.2.5. Antioxidant capacity

The antioxidant capacity of extracted (free phenols), hydrolyzed (bound phenols), and bioaccessibility of these phenols in the fruit samples was estimated using the following free radical scavenging methods expressed as Trolox equivalent antioxidant capacity (TEAC).

2,2-diphenyl-1-picrylhydrazyl (DPPH) assay

The stock solution for the analysis was prepared using 39.4 mg of DPPH in 100 ml of methanol and stored in the dark at -4°C until used. Later, 6ml from the stock DPPH solution was further diluted with 100 ml of methanol, to be used as a working solution. For the standard stock solution, 12.1 mg Trolox was dissolved in 50 ml methanol

(99.5% pure, v/v) and kept in the dark. Appropriate aliquots from Trolox of different concentrations were added to the working DPPH solution and kept in the dark for 30 min at room temperature. After 30 min, the absorbance was measured at 515 nm against pure methanol as blank, for the calibration of the standard curve and expressed as µmol of Trolox equivalent antioxidant capacity (TEAC) per gram.

The assay was conducted for all the extractable, hydrolyzable, and bioaccessible phenols, including both the fruit samples. To evaluate the antioxidant capacity of the fruit samples, 3900 µl of working DPPH solution was added to 100 µl sample aliquot and kept in the dark for 30 min at room temperature. The absorbance was measured at 515 nm for each sample from both cornelian cherry and blueberry. The analyses were carried out in triplicates for all the samples (Sahan et al. 2017). The inhibition rate was estimated using the following equation:

$$\% \text{ Inhibition} = (Abs_{control} - Abs_{sample}) / Abs_{control} \times 100 \quad (3.1)$$

where; $Abs_{control}$ is the absorbance of the blank solution (pure methanol), Abs_{sample} is the absorbance of the fruit samples

2,2´-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay

To determine the antioxidant capacity, a stock solution of ABTS with 2.45 mmol/L potassium persulfate ($K_2 S_2 O_8$) was prepared and kept at room temperature in the dark for 12-16 hours before use. Also, Trolox solution was prepared in 96% ethanol. For the calibration curve, the ABTS was further diluted with 96% ethanol (1:10 v/v), and small aliquots of Trolox mixed with diluted ABTS working solution at different concentrations was homogenized using a vortex and absorbance was recorded after 6 min of initial mixing at 734 nm against ethanol used as blank.

The fruit samples including extractable (free phenols), hydrolyzable phenols (bound phenols), and bioaccessible phenols were evaluated for antioxidant capacity by adding 50 µl of the fruit sample with 3.39 ml 96% ethanol, and 1 ml diluted ABTS and kept in

the dark for 6 min at room temperature; the absorbance was recorded at 734 nm using ethanol as a blank. The results were quantified as μmol of Trolox equivalent antioxidant capacity (TEAC) per gram (Apak 2008).

Cupric Reducing Antioxidant Capacity (CUPRAC) assay

The standard solutions of Copper chloride ($CuCl_2$. $2H_2O$; 1.0×10^{-2} M, in distilled water), neocuproine (7.5×10^{-3} M, in 96% ethanol), and pH 7.0 ammonium acetate (CH_3COONH_4; 7.708 g in 100 ml distilled water; w/v) buffer solution, and Trolox in 96% ethanol was prepared. For the standard curve, 1 ml of $CuCl_2$. $2H_2O$, 1 ml of neocuproine and 1 ml of pH 7.0 buffer mixture were added to (1-x) ml of distilled water and x ml of Trolox. The mixture was then let to stand in the dark for 30 min at room temperature before absorbance was measured at 450 nm against distilled water as blank. Similarly, for cornelian cherry and blueberries, the same procedure was applied, replacing x ml of Trolox with the fruit samples. The process was carried out in triplicates for both the fruit samples and the results were expressed as μmol of Trolox equivalent antioxidant capacity (TEAC) per gram (Sahan et al. 2017).

3.2.6. Total anthocyanins

Extraction for total anthocyanin content

For anthocyanin content, 0.5 g of sample (dry weight; dw) was mixed with 10 ml 1% HCL in methanol (MeOH) solution. The mixture was left to stand for 72 hours at room temperature. Later, the samples were centrifuged at 3500 rpm for 10 min, and the supernatant was transferred to a new 15 ml tubes. The extracts were stored at -4°C until used. The procedure was applied for all the different drying treatments, including both the fruit samples.

Chemical reagents

The pH 1.0 buffer solution was prepared by mixing 0.186 g of KCl (potassium chloride) in 100 ml of distilled water. By adding 0.63 ml of HCL (37% pure) to the mixture, the pH was brought to 1.0. The buffer solution was homogenized using a shaker water bath. The pH 4.5 buffer solution was prepared using 5.44 g sodium acetate ($CH_3COONa. 3H_2O$) in 100 ml distilled water and the pH was maintained by adding 2 ml of HCL (37%, pure).

Estimation of total anthocyanin content

The total anthocyanin (TA) content was determined using a pH differential method. For each extracted sample, two aliquots were prepared, one with a pH 1.0 buffer solution (1.0 ml sample + 4 ml pH 1.0 buffer), and another with a pH 4.5 buffer (1.0 ml sample in 4 ml pH 4.5 buffer). The mixture was gently mixed, and the absorbance was recorded at 657 nm and 530 nm against a blank. All the test were conducted as triplicates. The calculations were done using;

$$A = (A_{530} - A_{657})\, pH_{1.0} - (A_{530} - A_{657})\, pH_{4.5} \quad (3.2)$$

The results were quantified as cyanidin-3-glucoside equivalent in fresh and dry weight

3.2.7. Vitamin C content

The vitamin C content of dried cornelian cherry and blueberries were determined using the spectrophotometric analysis. The samples were treated with stabilizing buffer solutions, and later, the extracted filtrate was added to the 2,6-dichlorophenolindophenol solution, and the absorbance was measured at 520 nm.

Extraction and chemical preparation

The standard stock solutions were prepared as follows: 50 mg of L-ascorbic acid is dissolved with 0.4 % oxalic solution, and the solution was brought to a volume of 100 ml using distilled water, 15 g of solid metaphosphoric acid dissolved in 40 ml glacial acetic acid and 450 ml of distilled water, and 2,6-dichlorophenolindophenol solution ($12mg.L^{-1}$). From both the fruits 1g of the sample was dissolved in 10 ml metaphosphoric acid - acetic acid solution, homogenized and filtered.

Estimation of vitamin C

For the standard curve, 9 ml of 2,6-dichlorophenolindophenol solution was added to 1 ml of metaphosphoric acid - acetic acid solution, and the absorbance was recorded at 520 nm, against distilled water as blank. The value gives the L_1 absorbance. For the second step, 1 ml of the ascorbic acid solution, was added to 9 ml distilled water and used as a blank for reference. Later, to 9 ml of 2,6-dichlorophenolindophenol solution, 1 ml of ascorbic acid solution was added, and the absorbance was measured at 520 nm. The value gives L_2 absorbance. The final absorbance for the standard calibration curve of the ascorbic acid can be calculated by subtracting L_1 from L_2 ($L_1 – L_2$). Similarly, for all the extracted samples, L_1 and L_2 were calculated, and the results were expressed in $mg.100g^{-1}$.

3.2.8. Antimicrobial activity analysis

Extraction

The CC and BB extracts were prepared using 1 g of fruit sample from both the fruits, ground it using a mortar-pestle and then add 10 mL of 80% methanol solution. Shake the mixture gently, using a vortex mixer at room temperature for 2 h. Later filter the solution through a 0.45 mm filter paper, and centrifuge at 3500 rpm for 10 min. After centrifugation, take the supernatant and evaporate the methanol using a rotar evaporator

at 50°C and 1.98 mbar pressure. Once all of the methanol is evaporated add 5 ml double distilled water to the left concentrate and store at -4°C until used (Shen et al. 2014).

Determination of antimicrobial activity

To determine the antimicrobial activity of the prepared methanolic fruit extracts, standard agar disk diffusion and microwell diffusion methods were used. The standard disk diffusion method is employed to test the resistance or sensitivity of pathogenic bacteria against various antimicrobial compounds. During this process, a filter paper disk dipped into the extract solution are then placed on the agar plates, inoculated with bacterial strains, to check for the presence or absence of the bacterial growth around the disk. Similarly, for microwell diffusion method, a microwell is dug within the agar plate and the well is filled with an extract solution to check whether the diffusion of extract solution into agar have produced an inhibition zone.

Preparation and innoculation

From both the fruit samples, a total of 10 different extraction solutions were prepared (5 from each fruit). The 6 mm filter paper disks were impregnated with the prepared extraction solutions at 3 different concentrations (15µL, 30 µL, and 60 µL). These disks were then placed over the agar plates to let the excess solution dry off. Meanwhile, from a prepared subculture of *E.coli* a few individual colonies, with the help of a sterile swab, were diluted in a 2 ml sterile saline solution until the turbidity reaches the 0.5 Mc Farland standard (i.e., 5 $x10^8$ CFU mL^{-1}). This is done because for the results to be valid; the microbes should be in log phase.

Once the required turbidity was attained, the sterile swab was dipped in the saline solution and then Mueller-Hinton (MH) plates were inoculated by streaking the wet swab on all sides of the agar plate for even distribution. The step was repeated for all the six MH plates. Then with the help of a sterile forceps, impregnated microdisks for all the three concentrations were one by one placed on each MH plate. Once all the disks

were plated, the MH plates were then incubated at room temperature for 24 h (Hudzicki 2009).

Similarly, for microwell diffusion method, after the MH plates were innoculated with bacterial colonies, with the help of a sterile loop 80 µL microwells were dug out of the agar plate and filled with 80 µL extraction solutions for both the fruit samples. These plates after inoculation were then incubated at room temperature for 24 h (Hudzicki 2009).

3.2.9. Statistical Analysis

Results in this study are presented as mean values ± standard error estimation for all the tables. The data was analyzed with Jump 7.0, statistical program. Difference in sample were tested for statistical significance at $p < 0.01$ level. The correlation matrices for CC and BB were also evaluated as multivariate statistical analysis using Jump 7.0.

4. RESULTS AND DISCUSSION

The study was conducted for two different types of wild fruit varieties, namely cornelian cherry (CC) and blueberries (BB). Both the fruits were exposed to different types of drying methods such as- natural drying, convective hot air drying, microwave drying, and combined microwave-convective drying. The fruits were treated at 50°C, 70°C, and 90°C for convective drying and 100 W, 300 W, and 500 W for microwave drying; also the combination of all the drying temperatures with all microwave power outputs. The results for the drying methods for both cornelian cherry and blueberry are categorized as- drying time and specific energy consumption, color parameters, vitamin C content and total anthocyanin, total phenolic content and antioxidant capacity, and antimicrobial activity.

4.1. Drying time and specific energy consumption

During the drying process, the initial moisture content of cornelian cherry (CC) at 72.56 ±0.18% was reduced down to 10.27 ± 0.13%; whereas the moisture content of blueberries (BB) initially at 84.76 ± 0.20% was reduced to 10.03 ± 0.09%. Table 4.1 shows the various drying times and specific energy consumption for different drying methods. From the table, it is seen that 50°C has the longest drying time followed by 70°C for both the fruit varieties; whereas, the shortest drying time is seen for 500 W-90°C combination drying. For BB, the drying times at 500 W-90°C, 500 W-70, and 500 W-50°C are approximately closer to each other. The longest drying time at 50°C is 102 folds longer than the shortest drying time for CC. Similarly, for BB, the longest drying time at 50°C is 196.6 folds longer than the shortest drying time at 500 W-90°C. Among the two fruits BB has longer drying time for 50°C, which is 1.15 times more than CC. Furthermore, it can be inferred from the table that the convective drying lasts for longer durations whereas, combined drying methods and microwave drying methods have shorter time durations.

These results are in similarity with the literature. Also, the increase in temperatures shows a rapid decrease in drying times. These findings can be attributed to the fact that

higher temperatures cause rapid moisture evaporation, which leads to quick-drying and shorter durations.

The natural drying process took place inside the dark room, and for cornelian cherry lasted for 29 days while for blueberries the same drying process continued for about 22 days.

Table 4.1. Drying time and specific energy consumption for cornelian cherry and blueberry.

Drying	Drying time (min)		Specific Energy Consumption (kWh)	
Method	(CC)	(BB)	(CC)	(BB)
50°C	3060	3540	153	177
70°C	590	650	29.50	32.50
90°C	260	340	12.99	16.98
100 W	153	198	0.26	0.33
300W	100	82	0.50	0.41
500 W	50	64	0.42	0.53
100 W-50°C	150	160	7.75	8.06
100 W-70°C	130	90	6.69	4.65
100 W-90°C	118	88	6.07	4.52
300 W-50°C	68	76	3.73	4.15
300 W-70°C	62	74	3.40	4.06
300 W-90°C	52	68	2.66	3.73
500 W-50°C	46	22	2.20	1.26
500 W-70°C	38	20	1.75	1.15
500 W-90°C	30	18	2.92	1.05

CC, cornelian cherry; BB, blueberry; W, watt; min, minutes; kWh, kilowatt-hour

According to the data from Table 4.1, the highest energy consumption can be seen by 50°C in both CC and BB, followed by 70°C and the least values are found to be for 100 W. Among CC and BB, BB has the higher energy consumption, which is 1.15 times more than CC. The higher energy consumption is due to longer drying time, and the lesser values are due to higher power outputs. Therefore, it can be deduced that energy consumption and drying time are directly proportional to one another. From the data, it is found that the microwave drying has lower energy values compared to the combined

drying methods, this can be due to the combined energy consumption of both the temperature and microwave power outputs.

Horecki et al. 2018, conducted convective drying at 55°C, 60°C, and 70°C on fresh cornelian cherry fruits. The drying time lasted between 480 and 1200 min, with the most prolonged drying period for 55°C and the shortest for 70°C. The longest drying time at 50°C from our study is 2.55 time longer than this study, and the shortest drying time from this study is 1.84 folds more than our results at 90°C. Polatoglu and Bese 2017, conducted the convective drying of cornelian cherry at 50°C, 60°C, and 70°C temperatures with 0.4, 0.7, and 1.0 $m.s^{-1}$ air velocity. The study concluded that shorter drying times were observed with the increase in the temperatures. The drying time ranged between 18-71 h. The results from the study are similar to our data, which shows the decrease in drying time with the increase in temperature. López et al. 2010, carried out the drying of blueberries at 50°C, 60°C, 70°C, 80°C, and 90°C and found that with the increase in air-drying temperature, there is a decrease in the drying time, which is comparable to the observations from our study. Koyuncu et al. 2007, treated the fresh cornelian cherry with three different temperatures at 50°C, 60°C, and 70°C. It was found that the drying time lasted for 85, 45, and 29 h at 50°C, 60°C, and 70° C, respectively. The study also concluded that energy consumption decreases with increasing temperatures, which again is identical to our observations. Vega-Gálvez et al. 2009, performed the convective drying of blueberries at 60°C, 70°C, and 80°C with the shortest drying time 500 min for 80°C followed by 800 min for 70°C and the longest time 1400 min for 60°C. The study also concluded that with the increase in the airflow temperatures, there was a rapid decrease in the drying time. When compared with our data, the longest drying time at 50°C from our study is approximately 2.53 times longer than drying time at 60°C from this study. Also, the shortest time at 80°C from the study is 2.34 times more than our data at 90°C. Zielinska et al. 2016, under this study the blueberries were exposed to three different drying treatments such as- convective drying at 60°C and 80°C, microwave drying at 0.7 Wg^{-1}, and the combined microwave-convective drying. The study shows that with the increase in the drying temperature, the drying time decreases with the longest drying time of 1620 min for 60°C and the shortest period of 135 min for combined drying at 80°C-0.7 Wg^{-1}. These findings are

matching with our data. The comparison from both the study indicates that our longest drying time at 50℃ is 1.83 times more than the longest time at 60℃ in this study. Yemmireddy et al. 2013, applied two different temperature treatments (85℃ and 107℃) to fresh blueberries using different drying processes. The study results showed that the drying time at 85℃ for all the drying processes ranged from 168 min to 505.8 min, and at 107℃ ranged between 148.2 min and 361.8 min. This study also implies that the higher airflow velocity may have a direct influence on the drying time because increased air velocities help to increase the heat transfer coefficient, leading to reduced drying time. Kowalski et al. 2016, the study conducted using convective drying method alongside combined microwave-assisted drying method on fresh strawberries puts forward the results that convective drying is a very long-lasting process which takes about 1258 min, while the combination of microwave with convective drying causes a rapid moisture diffusion which leads to short drying periods reducing the time by 93% to approximately 82 min. Similar observations can be drawn from Table 4.1, which indicates the decrease in the drying periods for microwave-convective drying, followed by microwave drying than compared to drying time for convective drying. Also, the lower energy consumption values amounting to only 0.98 kWh were found for microwave-assisted convective drying; whereas the highest value to be 9.06 kWh for convective drying. Identical conclusions can be drawn from our study. Horuz et al. 2017, performed convective and hybrid drying on fresh sour cherries and calculated the total energy consumption for convective drying ranged from 3.84 to 14.57 kWh, while for microwave-assisted convective drying it lies between 1.38 to 5.21 kWh. The energy consumption values for convective drying in our study are much higher in comparison, with a difference of 90%. However, the values for hybrid drying are similar to our findings.

4.2. Color Parameters

Color is an essential parameter to determine the quality of dried fruits. Table 4.2 provides data on various color parameters for cornelian cherry. It indicates that the closest value for brightness *"L"* to that of the frozen fresh fruit is at 70°C followed by 100 W and the farthest value is found to be for natural drying. Similarly with regards to the redness coordinate *"a"* the highest value can be seen for frozen fresh fruit followed by 100 W and the lowest value for 500 W-50°C. The coordinate *"b"* for yellowness is highest for 50°C compared to the frozen fresh fruit and the lowest for 300 W-50°C. Chroma *"C"* and hue angle *"α"* has the highest values for 100 W and 500 W-50°C, respectively. The higher chroma values suggest that the color of the fuit is brighter, while the lower values indicate that the fruit color is more dull. The *α,* hue angle, when ranged between 0-30, shows the redness of the fruit. The values near to 0 means that the color change is more towards purple-red, while values closer to 30 suggest more of orange-red color. These results suggest that, when compared with the colorimetric characteristics of fresh fruits, the color changes observed in dried products is due to the loss of moisture content and dry matter concentrations. The lower values of *L* coordinate refers to the darkening of the fruits due to prolonged drying time, which influences the quality of the product significantly. Similarly, the lower readings for redness points towards the color loss and browning of the fruit surface, which could be because of the oxidation of anthocyanins (color pigment).

Table 4.2. Color parameter for cornelian cherry (CC) using various drying methods

Drying Method	Color Parameter				
	L**	a**	b **	C**	α**
Frozen Fresh	29.20±0.74^{a}	33.78±0.64^{a}	14.48±0.74^{a}	36.76±0.84^{a}	23.15±0.79^{g}
Natural drying	20.80 ±0.90^{hi}	5.73±0.22^{j}	2.80±0.41^{gh}	6.41± 0.37^{j}	25.46±2.50^{fg}
50°C	26.20±0.46^{bcd}	15.01±0.48^{d}	10.31±0.56^{b}	16.43±0.62^{ef}	29.26±2.02^{cdef}
70°C	27.46±1.42^{ab}	14.35±0.48^{de}	9.86±0.56^{bc}	17.55±0.70^{de}	34.03±0.79^{ab}
90°C	26.25±1.09^{bcd}	16.05±0.22^{c}	10.18±0.52^{b}	19.05±0.39^{c}	32.43±1.26^{abcd}
100W	26.83±1.06^{bc}	18.18±0.27^{b}	10.30±0.72^{b}	20.96±048^{b}	29.43±1.68^{cdef}
300W	26.65±1.46^{bc}	14.23±0.34^{def}	8.06±0.78^{d}	16.43±0.62^{ef}	29.26±2.02^{cdef}
500W	23.68±0.54^{efg}	7.40±0.33^{i}	4.70±0.39^{fg}	8.78±0.46^{i}	32.26±1.64^{abcd}
50°C-100W	24.23±0.34^{def}	12.26±0.26^{gh}	7.73±0.44^{d}	14.51±0.34^{gh}	32.10±1.57^{abcd}
50°C-300W	22.43±0.43^{fgh}	3.01±0.30^{k}	2.08±0.17^{i}	3.66±0.34^{k}	35.06±1.31^{a}
50°C-500W	21.58±0.64^{ghi}	2.96±0.21^{k}	2.18±0.09^{i}	3.68±0.21^{k}	35.35±1.31^{a}
70°C-100W	24.88±0.66^{cde}	13.65±0.48^{ef}	7.98±0.34^{d}	15.80±0.53^{ef}	30.31±1.00^{bcde}
70°C-300W	23.06±0.93^{efgh}	12.36±0.23^{gh}	5.38±0.21^{f}	13.50±0.22^{h}	23.58±0.86^{g}
70°C-500W	22.38±0.67^{fgh}	7.26±0.24^{i}	8.21±0.39^{gh}	8.21±0.35^{i}	27.33±1.96^{efg}
90°C-100W	24.85±0.60^{cde}	12.56±0.48^{gh}	8.38±0.38^{cd}	15.13±0.57^{fg}	33.73±0.85^{abc}
90°C-300W	23.73±0.77^{bcd}	13.26±0.31^{fg}	7.15±0.48^{de}	15.08±0.45^{fg}	28.16±1.40^{def}
90°C-500W	24.61±0.52^{cdef}	11.81±0.23^{h}	6.00±0.40^{ef}	13.26±0.22^{h}	26.86±1.70^{efg}

L, brightness/darkness; a , greenness/redness; b, yellowness/blueness; C, Chroma; α°, hue angle

** p<0.01 Column mean values with different superscripts are significantly different;±SE, standard error

Table 4.3 shows the readings for the colorimetric parameters in blueberry. After frozen fresh blueberries, the highest value for brightness is found to be for 90°C, followed by 50°C. The least values are shown for 100 W, which could be due to the exposure to microwave radiations for an extended period that caused damage to the outer surface of berries. The negative values for *b* parameter refer to the blueness and show the closest readings for natural drying to that of frozen fresh berries. The highest positive values of coordinate *b* at 500W-50°C refer to the browning of the fruit surface caused by the exposure to heat treatments. Likewise, the lower values of hue angle, *α*, indicates for microwave and combination drying methods are due to the damage of the fruit surface, which refers to the slight pinkish-red color of BB.

Table 4.3. Color parameters for blueberries (BB) using various drying methods

Drying Methods	Color Parameter				
	L**	a**	b**	C**	α**
Frozen Fresh	24.21±0.77^{a}	0.38±0.08^{ef}	-1.58±0.05^{i}	1.65±0.05^{de}	280.41±4.40^{e}
Natural Drying	22.63±1.09^{abcd}	0.21±0.05^{f}	-1.51±0.09^{i}	1.53±0.09^{ef}	278.48±2.35^{e}
50°C	22.93±0.78^{abc}	0.90±0.10^{c}	-0.60±0.06^{gh}	1.10±0.11^{h}	325.51±2.89^{c}
70°C	22.45±0.40^{abcde}	0.71±0.08^{cd}	-0.23±0.04^{f}	0.83±0.06^{i}	336.51±7.47^{b}
90°C	23.73±0.57^{ab}	0.80±0.06^{cd}	-0.28±0.04^{f}	0.86±0.06^{i}	340.50±3.14^{ab}
100W	19.63±0.81^{fgh}	0.76±0.07^{a}	1.31±0.03^{h}	1.53±0.02^{a}	59.95±2.77^{a}
300W	20.55±0.71^{bcdef}	3.43±0.08^{f}	-0.78±0.13^{f}	3.53±0.08^{j}	347.50±3.01^{d}
500W	22.16±0.35^{h}	0.26±0.04^{cd}	-0.36±0.07^{bcd}	0.48±0.04^{ef}	310.98±8.74^{f}
100W-50°C	22.66±0.14^{abcd}	0.80±0.03^{cd}	0.90±0.07^{e}	1.20±0.07^{gh}	49.98±1.11^{f}
100W-70°C	20.16±0.48^{gh}	0.91±0.03^{c}	1.48±0.05^{b}	1.75±0.04^{d}	57.95±1.05^{f}
100W-90°C	21.1±0.57^{cdefgh}	0.73±0.04^{cd}	1.28±0.04^{bcd}	1.50±0.03^{ef}	59.90±0.99^{f}
300W-50°C	20.65±0.43^{efgh}	0.90±0.06^{c}	1.30±0.06^{bcd}	1.61±0.06^{de}	55.78±2.07^{f}
300W-70°C	20.45±0.40^{fgh}	0.88±0.06^{c}	1.25±0.04^{cd}	1.55±0.03^{def}	55.78±2.25^{f}
300W-90°C	20.96±0.14^{defgh}	0.91±0.12^{c}	1.45±0.02^{bc}	1.70±0.08^{de}	54.90±2.16^{f}
500W-50°C	20.10±0.77^{h}	1.46±0.10^{b}	1.81±0.04^{a}	2.35±0.05^{b}	51.60±1.58^{f}
500W-70°C	20.10±0.44^{h}	1.28±0.09^{b}	1.48±0.07^{b}	1.96±0.10^{c}	49.71±1.92^{f}
500W-90°C	21.96±0.99^{bcdefg}	0.78±0.12^{cd}	1.15±0.14^{d}	1.35±0.14^{fg}	55.15±1.16^{f}

L, brightness/darkness; a greenness/redness; b, yellowness/blueness; C, Chroma; α°, hue angle

** p<0.01 Column mean values with different superscripts are significantly different.

Zielinska et al. 2016, shows similar results for colorimetric changes, as shown in our study. The study was conducted on fresh blueberries and berries dried using convective drying, microwave drying, and combined microwave-convective drying as single as well as a multi-stage process. The lowest reading for brightness was found to be for convective drying, which is indifference with our findings. The measurements for *b* coordinate are comparable with our results and draws similar conclusions to our observations. Yemmireddy et al. 2013, under the research study, the fresh blueberries were exposed to two different temperatures (85°C and 107°C) and the brightness value *L* was between 14.81 and 16.29, which is lower than the findings from our study; whereas, Chroma *C* values in this study are higher to that of ours. The hue angle values are in agreement with our readings. Horecki et al. 2018, shows that the total color change in CC after convective drying ranges from 10.47% to 14.95%, with the least

color change at 55°C and the highest at 70°C. This result indicates the negative correlation between color preservation and oxidation of natural pigments. Kowalski et al. 2016, performed similar experiments with fresh strawberries and found a significant color change between the fresh and dried product suggesting that the continuous application of hot air with microwaves led to the discoloration due to the degradation of natural dyes. The study found the lowest color change for convective-ultrasound drying and the highest value for color change in convective-microwave drying, which again is identical to our findings. These results could be attributed to the fact that microwave-assisted hot-air dried strawberries have no difference compared to convective drying due to pigment loss related to the higher temperature attained by samples during the process, which leads to surface damage.

Figure 4.1 indicates the effect of different drying treatments on the shape, color, and physical appearance of the CC fruit samples. In the picture, it is shown that compared to fresh CC samples, microwave drying samples have a darker color, and the edges of the fruit sample are seen to be burnt. It can also be seen that at the higher microwave powers, the loss of natural pigments is higher when compared with that of the higher convective drying temperatures. At 100 W, the red color of the fruit is more prominent than at other temperatures.

Figure 4.1. Samples of cornelian cherry after drying treatments. **(a)** Fresh CC sample, **(b)** CC after natural drying, **(c)** CC at 50°C, **(d)** CC at 70°C, **(e)** CC at 90°C, **(f)** CC at 100 W, **(g)** CC at 300 W, and **(h)** CC at 500 W

Figure 4.2. CC samples after combined microwave-convective drying

Moreover, from Figure 4.2, it can be easily distinguished that the combination of convective drying temperatures with lower microwave power outputs produces better results than that of the higher microwave powers. These results are in accordance with the other studies from the literature

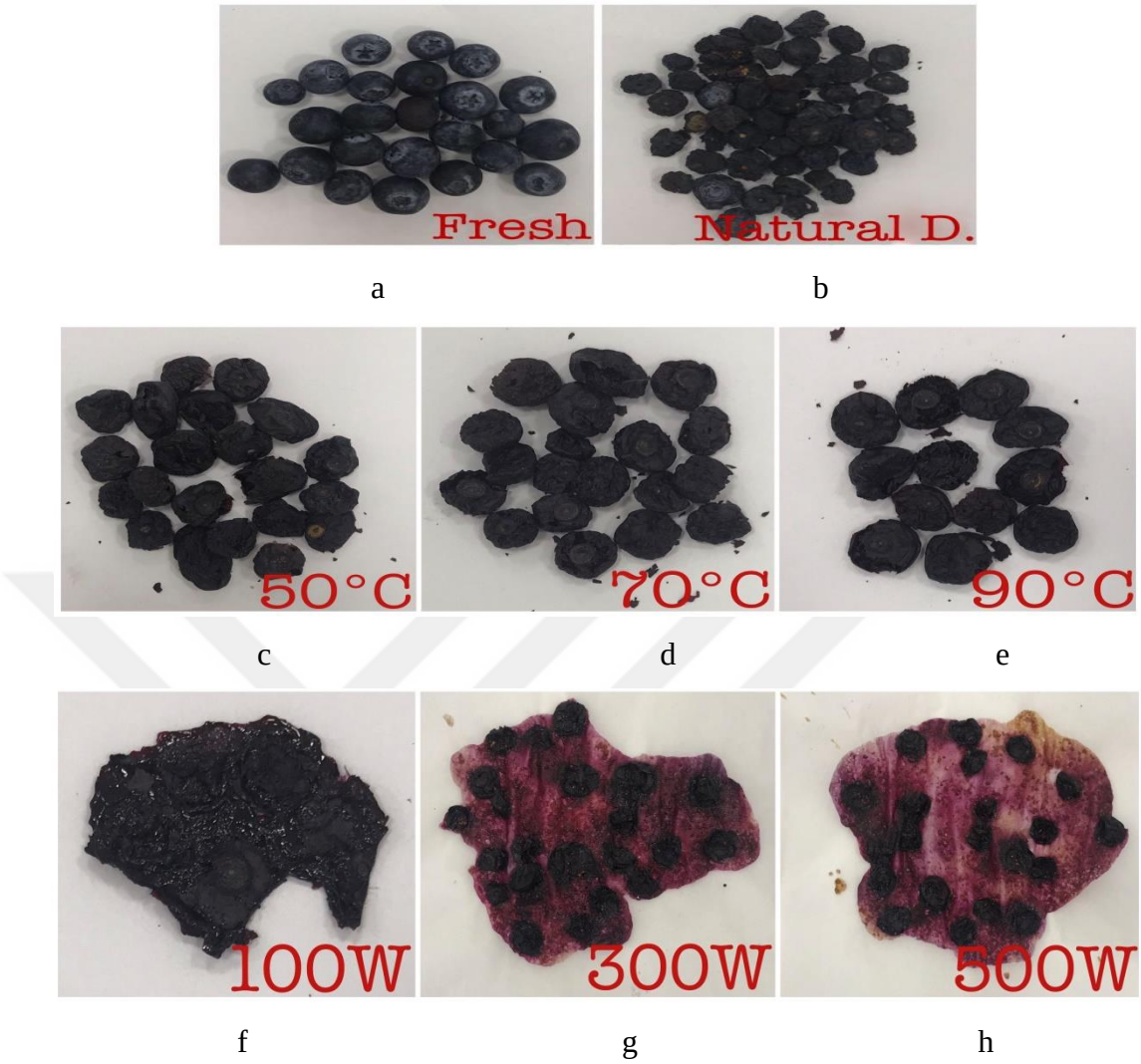


Figure 4.3. Samples of BB after treatment with different drying methods. **(a)** Fresh blueberry sample, **(b)** Natural drying sample, **(c)** BB at 50°C **(d)** BB at 70°C **(e)** BB at 90°C, **(f)** BB at 100 W, **(g)** BB at 300 W, and **(h)** BB at 500 W

Figure 4.3 depicts the changes in the blueberry fruit samples after the application of different drying methods. From the figure, it is clear that microwave drying treatments has led to the breakage of fruit surface and thus, the berries have lost their shape and natural color. When compared, the convective dry samples, have shown better results in terms of the fruit shape and color. Furthermore, Figure 4.4. ponits towards the destruction of shape and loss of color in BB after exposure to combined drying treatments. These results can be justified by the fact that during microwave drying, the internal and surface temperature of the fruit sample increases beyond the threshold

temperature, which leads to the disintegration of the fruit material. The results shown in the figures are in accordance with the results concluded from Table 4.3.

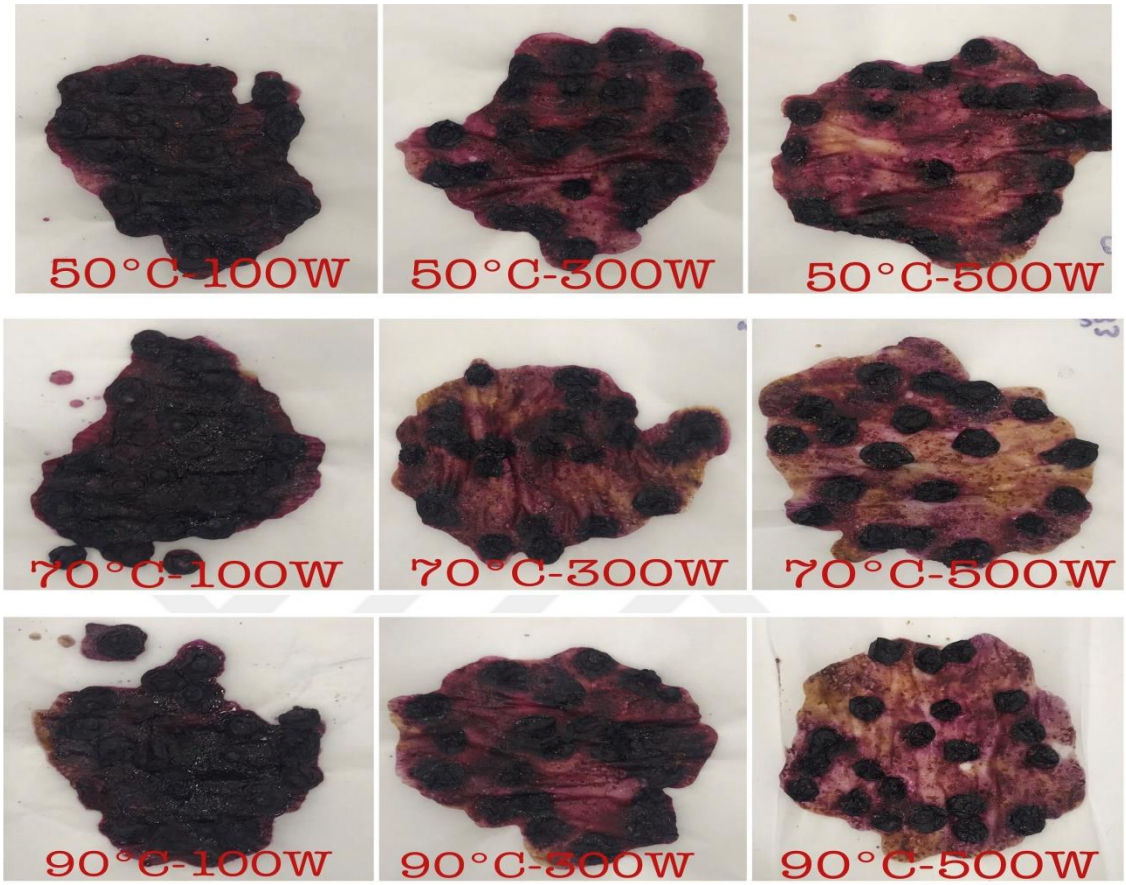


Figure 4.4. BB samples after exposure to combined microwave-convective drying

4.3. Anthocyanin and vitamin C content

Anthocyanin is a biochemical compound which is a natural pigment and gives the red color to the berry fruits. Table 4.4 depicts the total anthocyanin content of both CC and BB. The highest value for CC was found in frozen fresh fruits followed by 70°C and 300 W; also the least value can be seen for 500W-50°C, followed by natural drying. Among the convective drying methods, the total loss of anthocyanin for CC ranged between 71% and 82% with the highest loss found to be at 90° C. Similarly, among microwave drying treatments, the total loss ranged between 42% and 52%, which is less compared to the convective drying methods. For combined temperature treatments, the

loss ranged between 67% and 92%, with the highest reduction rate being at 500 W-50°C. The similarity in the loss range between convective and combination drying methods is suggested to be because of the higher temperature attained by the product during exposure to microwaves, which leads to the destruction of the biochemical composition of the fruits.

Table 4.4. Total anthocyanin (TA) content in cornelian cherry (CC) and blueberries (BB)

Drying	**Total Anthocyanin Content mg(CDE) g^{-1} (fw)**	
Methods	**Cornelian cherry (CC)^{ns}**	**Blueberries (BB)****
Frozen Fresh	3.68±0.010^{ab}	6.74±0.130^{h}
Natural drying	0.34±0.001^{b}	12.59±0.070^{d}
50°C	1.04±0.030^{b}	4.04±0.230^{j}
70°C	2.61±0.010^{ab}	5.09±0.200^{i}
90°C	0.63±0.005^{b}	7.61±0.160^{g}
100W	1.75±0.010^{b}	16.02±0.260^{b}
300W	2.11±0.020^{b}	17.41±0.220^{a}
500W	1.86±0.060^{b}	13.26±0.310^{c}
100W-50°C	0.85±0.009^{b}	17.10±0.160^{a}
100W-70°C	0.86±0.005^{b}	11.42±0.020^{e}
100W-90°C	0.52±0.020^{b}	17.30±0.090^{a}
300W-50°C	0.60±0.020^{b}	9.07±0.150^{f}
300W-70°C	1.21±0.160^{b}	12.81±0.240^{cd}
300W-90°C	1.08±0.005^{b}	8.10±0.180^{g}
500W-50°C	0.27±0.006^{b}	2.10±0.010^{k}
500W-70°C	0.60±0.010^{b}	9.22±0.130^{f}
500W-90°C	0.52±0.040^{b}	12.48±0.280^{d}

mg, milligram; CDE, cyanidin-3-glucoside equivalent; g, gram; fw, fresh weight

** ($p<0.01$) Column mean values with different superscripts are significantly different;ns, non-significant

Table 4.4 also shows the anthocyanin content for BB with the highest readings at 300 W, followed by 100 W-90°C and 100 W-50°C. Similar to CC, the lowest reading for BB can also be seen at 500 W-50°C, with a loss of 88%. The anthocyanin content in BB for natural drying is 1.86 times more than that in frozen fresh fruit. Moreover, the anthocyanin in BB for 300 W is 2.58 times higher than frozen fresh berries. The range for a total loss of anthocyanin in BB for convective drying lies between 56% and 96%,

with the least values of loss at 90°C. For microwave and combination drying treatments, the range is between 8% to 23% and 2% to 88%, respectively. Moreover, the loss for convective drying is more compared to the losses for microwave drying; also, the range of loss among convective and combination drying methods are close to one another.

Gunduz et al. 2013, examined the total anthocyanin content in different ripening stages of CC and found to be in between the range of 4.9 and 65.0 µg (CDE) g^{-1} fw. Cetkovská et al. 2014, studied different varieties of cornelian cherry found in the Czech Republic and found that the total anthocyanin content ranged between 61 and 347 mg kg^{-1} fw. The study also suggested that the highest values for anthocyanins can be found in the varieties from Turkey and Iran (1068-4421 mg kg^{-1}). These findings are in agreement with our readings. Biaggi et al. 2018, examined the physico-chemical characters of CC and found the total anthocyanin content to be at 134.71 mg (CDE) 100 g^{-1} fw, which is comparable to our results. The study also concludes that anthocyanins comprise about 69% of the total polyphenols found in CC, making the fruit a vital source of natural antioxidant. Horecki et al. 2018, compared the total anthocyanin content of CC for different drying methods. The study calculated the total anthocyanin content in fresh cornelian cherry to be 1.47 g (CDE) $100g^{-1}$ fw, which is approximately 4-folds more than our results. The loss of anthocyanin for convective drying found in this study lies between 66.4% and 81.8%, which is comparable to our results (71%-97%). Kalt et al. 1999 (a), tested different berries for physico-chemical properties and found that the total anthocyanin content in fresh blueberries ranged from 2.67 to 4.35 µmol of Mal-3-glu. g^{-1} fw. Kalt et al. 1999 (b), tested various species and genotypes of fresh blueberries for their phenolic and antioxidant capacity. The study found out the anthocyanin ranged between 1.00 and 3.70 mg g^{-1}fw. These values are very low compared to our readings. Hariram et al. 2014, suggested that the total anthocyanin content in blueberries ranged between 25-495 mg g^{-1} fw, which is quite high compared to previous findings. The differences in the measurements can be because of the difference in analytical and extraction methods used. Kraujalyté et al. 2015, studied the antioxidant capacity and total phenols among different genotypes of blueberries and found the total anthocyanin content to be between 0.62 and 14.10 mg $100mL^{-1}$ fresh fruit extract, which is not dissimilar to our findings. Hassanpour et al. 2011, tested the different varieties and

genotypes of CC for biochemical composition and calculated the total anthocyanin to be between 106.89 and 442.11 mg $100g^{-1}$ fw. These results are not contradictory to our results.

Table 4.5. Total ascorbic acid content in cornelian cherry and blueberries for different drying methods.

	Ascorbic Acid Content mg $100g^{-1}$ (dw)	
Drying Method	**Cornelian Cherry (CC)****	**Blueberries (BB)****
Frozen Fresh	64.45 ± 0.003^{a}	40.29 ± 0.012^{a}
Natural drying	38.95 ± 0.008^{ab}	17.35 ± 0.013^{efg}
50°C	7.92 ± 0.019^{gh}	13.30 ± 0.004^{j}
70°C	8.70 ± 0.008^{fgh}	26.23 ± 0.006^{c}
90°C	12.90 ± 0.002^{defg}	15.22 ± 0.015^{i}
100 W	19.05 ± 0.004^{ab}	17.56 ± 0.003^{f}
300W	20.08 ± 0.008^{abcd}	21.15 ± 0.004^{ef}
500 W	25.02 ± 0.014^{ab}	27.55 ± 0.002^{b}
100 W-50°C	2.98 ± 0.007^{h}	3.31 ± 0.007^{m}
100 W-70°C	3.30 ± 0.017^{defg}	6.02 ± 0.004^{kl}
100 W-90°C	5.81 ± 0.010^{abc}	15.27 ± 0.002^{fgh}
300 W-50°C	2.55 ± 0.002^{fgh}	15.25 ± 0.002^{gh}
300 W-70°C	4.65 ± 0.004^{bcd}	3.06 ± 0.005^{ef}
300 W-90°C	2.91 ± 0.003^{efgh}	5.89 ± 0.001^{l}
500 W-50°C	3.40 ± 0.004^{defg}	6.25 ± 0.001^{k}
500 W-70°C	5.36 ± 0.025^{bcd}	6.23 ± 0.005^{k}
500 W-90°C	5.79 ± 0.004^{abc}	15.23 ± 0.002^{fgh}

mg, milligram; g, gram; dw, dry weight

** $p<0.01$ Column mean values with different superscripts are significantly different.

Ascorbic acid is an essential nutritive quality index, as it is highly unstable and sensitive to light, temperature, and oxygen, therefore mostly used as an indicator to determine the final results. Table 4.5 depicts the total ascorbic acid (TAA) values for both cornelian cherry CC and blueberries BB. The highest values of TAA, for both the fruits, are shown in frozen fresh samples, followed by natural drying for CC and 500 W for BB. The lowest values of TAA in CC are at 300 W-50°C, and in BB are at 300 W-70°C. The total ascorbic acid loss for convective drying in CC lies between 79% and 87%; whereas, the TAA loss for microwave and combination drying ranges from 61% to 70%

and 91% to 96%, respectively. The loss of ascorbic acid is less in microwave drying compared to that of convective drying, which is less than combination drying.

Furthermore, the TAA in blueberries for convective drying shows a loss of 62% to 66 %, and for microwave drying treatments it ranges from 32% to 57%; whereas, for combination drying this ranges between 61% and 92%, which is higher than both convective and microwave drying. When compared to the measurements of CC, the loss for convective and microwave drying in BB is far less, while for combination drying, the readings for both the fruits are in close range to one another.

Tural and Koca 2008, investigated 12 different varieties of CC for physico-chemical composition and found that the TAA ranged between 0.16-0.88 mg g^{-1} fresh fruit, which is in close range to our readings. Polatoglu and Bese 2017, found about 42% to 54% degradation in the vitamin C content of CC after heat application using convective drying. This result is dissimilar to our readings, with approximately a 2-fold difference. The loss of TAA in our study is higher than that of this work. The application of varied analytical methods can explain the difference in the readings. However, the conclusions drawn from both the studies imply that ascorbic acid degradation occurs due to extended heat treatments. López et al. 2010, stated that during convective drying, there was a loss of 92% at 80°C in the TAA content of blueberries. In our study, the loss at 90°C was estimated to be about 62%, which is less compared to this study. In conclusion, dehydration has a direct influence on the loss of vitamin C in blueberries. Cetkovská et al. 2014, found the TAA of different genotypes of CC and estimated it to be in the range of 199 to 433 mg kg^{-1} fresh fruit (i.e, 19.9 to 43.3 mg $100g^{-1}$ fw). These results are in a similar range to that of ours. The study also, suggests that the varieties of CC from Turkey have higher TAA values ranging from (160 to 767 mg kg^{-1} fw). Biaggi et al. 2018, compared the chemical composition of cornelian cherry to investigate the biochemical potential of CC as a superfood. In this, the vitamin C in fresh CC fruit is found to be 61.43 mg $100g^{-1}$ fw, which is in the range from various other studies (from 31.70 to 99.52 mg $100g^{-1}$ fw. The TAA for CC in our study is within the range mentioned in this study. Horeckci et al. 2018, found that the loss of TAA content in CC after convective drying is about in between 55.53% to 74.43%, which is close to our

readings where the loss is estimated to be around 79% to 87%. Kalt et al. 1999 (b), estimated that the TAA of fresh blueberries come in the range of 7-20 mg $100g^{-1}$ fw, which is in close proximity of our readings. Horuz et al. 2017, summarized that the total loss of TAA content in sour cherries after exposure to convectional drying method was around 70%.

4.4. Total phenolic content and antioxidant capacity

4.4.1. Total phenolic content (TPC) of cornelian cherry (CC)

The phenolic compounds present in fruits and vegetables, despite their poor bioavailability and solubility, are an essential source of antioxidants, thus have many health benefits. Therefore, the phenols are studied for their anticancer and anti-microbial properties as well as a natural preservative. The total phenolic content of CC in terms of extractable (unbound phenols) and hydrolyzable (bound phenols) is given in Table 4.6. In this table, the measurements included are according to the highest values of total ascorbic acid content.

Table 4.6. Total phenolic content (TPC) of cornelian cherry (CC)

Drying Methods	**Total Phenolic Content (mg GAE $100g^{-1}$ fw)****			
	E (Extractable)	**H (Hydrolyzable)**	**B (Bioaccessible)**	**TB%**
Frozen Fresh	579.68 ± 21.12^{b}	698.47 ± 3.94^{a}	151.63 ± 7.66^{e}	11.86 ± 0.31^{i}
Natural drying	455.83 ± 2.58^{c}	261.97 ± 2.69^{g}	146.57 ± 2.30^{e}	20.42 ± 0.32^{gh}
50°C	147.41 ± 3.72^{g}	346.14 ± 10.32^{de}	142.91 ± 2.03^{b}	28.96 ± 0.25^{a}
70°C	363.03 ± 2.23^{e}	359.09 ± 7.32^{cd}	162.33 ± 1.97^{d}	22.48 ± 0.36^{f}
90°C	272.11 ± 1.49^{f}	364.72 ± 3.68^{c}	175.28 ± 3.79^{c}	27.52 ± 0.53^{e}
100W	271.83 ± 1.95^{f}	318.83 ± 1.23^{f}	203.99 ± 1.49^{b}	34.54 ± 0.28^{b}
300W	377.10 ± 1.97^{d}	335.16 ± 6.60^{e}	$228.79 \pm 0.49a$	32.13 ± 0.40^{c}
500W	367.81 ± 1.01^{de}	655.12 ± 2.58^{b}	199.20 ± 1.95^{b}	19.47 ± 0.22^{h}

mg, milligram; GAE, Gallic acid equivalent; g, gram; TB%, percentage bioavailability of phenols; fw, fresh weight;
** $p<0.01$ Column mean values with different superscripts are significantly different

The highest TPC for extractable phenols is found to be at frozen fresh fruit samples and followed by natural drying, and for hydrolyzable phenols, the highest value is for frozen fresh samples, then for 500W. The lowest values for extractable phenols is at 50°C, while for hydrolyzable phenols the values are the least in natural drying. The table also provides information on the bioavailability of these phenols, which has the highest value at 100 W, and the least for frozen fresh fruit samples. The bioavailability of these phenols is essential, as it determines whether the body will absorb the phenols after consumption.

For extractable phenols, the loss of TPC after convective drying is around 50.96%, which is in a similar range with the findings of Horeckci et al. (2018). Moreover, for hydrolyzable phenols, this value is around 51%. Similarly, the average loss after microwave drying for both extractable and hydrolyzable phenols is around 41.3% and 37.4%, respectively. Moldovan et al. 2016, determined the TPC for CC to be 489.94 ± 17.88 mg $100g^{-1}$ fw expressed as gallic acid equivalents in fresh fruit extracts, which is in agreement with our readings. Tural and Koca 2008, determined the TPC of fresh CC to be 437 mg $100g^{-1}$ fw. These values are comparable to the findings of our study. Hassanpour et al. 2011, investigated different genotypes of CC for their antioxidant capacity and total phenolic content. The study found the TPC range between 1097.19 and 2695.75 mgGAE $100g^{-1}$fw. These values are higher than our readings, which ranges in between 151.63 to 698.47 mg GAE $100g^{-1}$. Horuz et al. 2017, provided information on the TPC of fresh sour cherry, which was found to be around 1234.30 mg GAE $100g^{-1}$ dry basis (db). The TPC of dried sour cherries under convectional and hybrid drying was also estimated in this study and was found to be in the range of 225.52 and 385.85 mg GAE $100g^{-1}$db. These results show a loss of 68 % to 87% in the total TPC of dried sour cherries, which is comparable with the total loss of TPC in CC from our study. Cosmulescu et al. 2019, calculated the TPC of wild genotypes of CC and showed it to be 266.65 mg GAE $100g^{-1}$ fw, which is less than our readings. These differences in the result can be attributed to the genetic factors and the ability to synthesize secondary metabolites. As it is known from many previous studies, polyphenols are challenging to extract and stabilize; therefore, the variation in TPC can be justified. Gunduz et al. 2013, this study analyzed phenols, anthocyanins, and antioxidant capacity at different

ripening stages of CC fruit and found that phenols ranged from 8063 to 4062 µg GAE $100g^{-1}$ fw. The results depict a decreasing trend in the TPC of CC with each maturing stage, thus the highest value being at the yellow stage and the lowest value at the dark red stage.

4.4.2. Total phenolic content (TPC) of blueberries (BB)

Table 4.7 shows the TPC of both extractable and hydrolyzable phenols in BB. The values in this table are included based on the highest ascorbic acid content of BB. From the table, it can be seen that for the extractable phenols (non-bound phenols), the highest TPC is found to be at 300 W followed by 90°C and the least value for frozen fresh fruit samples, which is different from that for CC. Similarly, the highest values for hydrolyzable (bound phenols) can be found for natural drying, followed by 70°C, and the least values for frozen fresh fruit samples. The bioavailability of these is the least at 90°C and 50°C, and the highest at 100 W followed by 500 W. Compared with the values in frozen fresh BB samples for extractable phenols, the average increase in the values is by 89%, and for hydrolyzable phenols, these values are increased by 77%.

Table 4.7. Total phenolic content of blueberries (BB)

	Total Phenolic Content (mg GAE $100g^{-1}$ fw)**			
Drying Methods	**E (Extractable)**	**H (Hydrolyzible)**	**B (Bioaccessible)**	**TB%**
Frozen Fresh	118.68 ± 2.03^{g}	101.81 ± 2.85^{g}	83.71 ± 4.80^{g}	37.92 ± 1.72^{d}
Natural drying	707.41 ± 22.13^{c}	448.51 ± 6.49^{a}	437.82 ± 15.61^{a}	37.92 ± 1.79^{d}
50°C	584.66 ± 3.34^{d}	325.79 ± 3.90^{c}	243.03 ± 6.82^{f}	26.69 ± 0.66^{f}
70°C	567.01 ± 25.67^{d}	368.01 ± 1.68^{b}	304.96 ± 9.76^{d}	32.65 ± 1.12^{e}
90°C	1043.27 ± 23.26^{b}	195.18 ± 5.37^{f}	272.87 ± 9.36^{e}	22.08 ± 1.20^{g}
100W	271.20 ± 1.13^{f}	291.80 ± 6.91^{d}	314.13 ± 2.82^{d}	55.81 ± 0.88^{a}
300W	1148.83 ± 22.62^{a}	203.06 ± 2.97^{f}	367.45 ± 9.00^{bc}	27.22 ± 1.07^{f}
500W	584.59 ± 50.09^{d}	297.4 ± 5.71^{d}	385.46 ± 2.45^{b}	44.05 ± 3.02^{b}

mg, milligram; g, gram; GAE, gallic acid equivalent; fw, fresh weight; TB%, percentage bioavailability of phenols; ** $p<0.01$ Column mean values with superscripts are significantly different

López et al. 2010, the study showed the TPC for fresh and convectional dried BB. The initial phenolic content at 1058.28±16.51 mgGAE $100g^{-1}$ db blueberries sample, followed by a rapid deduction in the TPC after exposure to the heat treatments. This study associates the loss of TPC with the long drying periods at low temperatures. These results are in contradiction with our results where the least values were observed within the fresh fruit samples. Hariram et al. 2014, reports the TPC in fresh BB to be within the range of 261-585 mg g^{-1} fresh weight, which is quite high in comparison to our findings. Kraujalyte et al. 2015, studied various varieties and genotypes of blueberries and found that the TPC range from 0.85 to 2.81 mg GAE mL^{-1} fresh fruit extract. These measurements were in similarity with previous research works, which suggests a similar result. The study stated that the variation in the TPC of BB can be because of the interaction of the reagent with other reducing ability possessing compounds.

Total antioxidant capacity (TAC)

The antioxidant capacity is estimated as the Trolox equivalent antioxidant capacity (TEAC) and be mainly categorized under three methods, namely- ABTS, DPPH, and CUPRAC.

4.4.3. TAC of Cornelian cherry (CC)

ABTS method

Table 4.8 (a) shows values for the total antioxidant capacity (TAC) using the ABTS method. The values included in the table are according to the highest values of ascorbic acid content. From the table, it can be seen that the extractable phenols have a higher antioxidant capacity at 500 W, followed by 300 W, and then at 90°C; whereas, the lowest antioxidant capacity is shown by natural drying and 50°C. Moreover, for hydrolyzable phenols, the highest antioxidant capacity is at 70°C, followed by frozen fresh fruit samples and then at 90°C; natural drying shows the least values for antioxidant capacity in hydrolyzable phenols. The percentage bioavailability values for

extractable and hydrolyzable phenols are highest for the natural drying and the lowest for 90°C. The reason for this variation can be justified by the conclusion drawn from many previous studies, that although the phenols might be extractable and show high antioxidant capacity; these phenols do not have bioaccessibility.

Table 4.8 (a). Trolox equivalent antioxidant capacity (TEAC) of cornelian cherry (CC) using the ABTS method

Drying Methods	Total Antioxidant Capacity (µmol Trolox 100g^{-1} fw)**			
	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	113.11 ± 2.16^{f}	74.91 ± 0.97^{b}	35.99 ± 0.19^{h}	19.15 ± 0.26^{f}
Natural drying	78.36 ± 0.58^{h}	38.86 ±1.23^{f}	37.78 ± 0.34^{g}	32.24 ± 0.81^{b}
50°C	79.69 ± 0.72^{h}	68.66 ± 0.23^{c}	44.69 ± 0.52^{e}	30.13 ± 0.52^{cd}
70°C	102.47 ± 0.72^{g}	148.86 ± 0.44^{a}	55.89 ± 0.38^{c}	22.24 ± 0.16^{e}
90°C	142.87 ± 4.21^{c}	73.58 ± 0.86^{b}	40.23 ± 0.91^{f}	18.62 ± 0.83^{f}
100W	122.59 ± 0.87^{e}	56.09 ± 0.58^{e}	57.36 ± 0.90^{bc}	32.10 ± 0.43^{b}
300W	179.95 ± 1.91^{b}	61.21 ± 1.14^{d}	75.36 ± 0.29^{a}	31.26 ± 0.49^{bc}
500W	233.83 ± 2.73^{a}	67.46 ± 0.72^{c}	57.69 ± 0.38^{b}	19.15 ± 0.14^{f}

µmol, micromole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

DPPH method

Table 4.8(b), contains the data regarding the antioxidant capacity of CC using DPPH method. The table includes values in accordance with higher ascorbic acid content. The table depicts the highest antioxidant for extractable phenols at 500 W, followed by 300 W and then 90°C; whereas the lower antioxidant capacity is shown by natural drying, followed by 50°C. These readings are identical to that of the ABTS method.

Table 4.8 (b). Trolox equivalent antioxidant capacity (TEAC) in cornelian cherry (CC) using DPPH method

Drying Methods	Total Antioxidant Capacity (µmol Trolox 100g^{-1} fw)**			
	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	113.11 ± 2.16^{e}	73.58 ± 2.92^{b}	35.99 ±0.18^{f}	19.28 ± 0.17^{d}
Natural drying	62.73 ± 4.39^{h}	41.52 ± 3.13^{e}	37.78 ±0.33^{f}	36.41 ± 1.77^{b}
50°C	81.35 ± 2.28^{f}	69.72 ± 1.26^{b}	44.20 ± 0.96^{d}	29.29 ± 1.06^{c}
70°C	107.46 ± 4.95^{e}	149.03 ± 0.43^{a}	54.80 ± 0.78^{c}	21.40 ± 0.72^{d}
90°C	142.04 ± 2.94^{c}	73.58 ± 0.86^{b}	40.77 ± 1.44^{e}	18.95 ± 1.01^{d}
100W	127.58 ± 4.36^{d}	58.08 ± 2.07^{d}	57.36 ± 0.89^{b}	30.91 ± 0.76^{c}
300W	179.95 ± 1.91^{b}	63.87 ± 2.42^{c}	75.36 ± 0.28^{a}	30.92 ± 0.42^{c}
500W	233.83 ± 2.73^{a}	69.39 ± 2.23^{bc}	58.23 ± 0.66^{b}	19.20 ± 0.19^{d}

µmol, micromole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

Similarly, for hydrolyzable phenols, the highest antioxidant capacity is found to be at 70°C, followed by frozen fresh and 90°C, both have the same readings; while the lower antioxidant capacity is shown by natural drying, which again is similar to that of the ABTS method. The least bioavailability of the phenols is shown by 90°C, followed by 500 W and then frozen fresh samples. These results are comparable with the values from the ABTS method.

CUPRAC method

Table 4.8 (c) shows the antioxidant capacity for CC using the CUPRAC method. The values included in the table are according to the highest ascorbic acid content. It is clear from the table that the antioxidant capacity of the extractable phenols in CC samples is highest for natural drying, followed by frozen fresh fruit samples, while the lowest values are at 50°C and then at 70°C. The highest antioxidant value for hydrolyzable phenols is found in frozen fresh fruit samples, followed by 500 W and then at 70°C. Natural drying and 300 W shows the lowest antioxidant capacity for hydrolyzable phenols.

Table 4.8. (c) Trolox equivalent antioxidant capacity (TEAC) in cornelian cherry (CC) using the CUPRAC method

Drying Methods	Total Antioxidant Capacity (mol Trolox g^{-1} fw)**			
	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	624.86 ± 5.41^{b}	1494.81 ± 56.58^{a}	49.97 ± 2.99^{c}	2.36 ± 0.16^{c}
Natural drying	680.99 ±5.40^{a}	472.07 ± 16.49^{e}	21.70 ± 1.44^{c}	1.88 ± 0.11^{c}
50°C	203.92 ±6.23^{h}	1087.38 ± 20.47^{c}	85.72 ± 2.99^{c}	6.64 ± 0.13^{bc}
70°C	231.98 ±89.64^{g}	1384.64 ± 59.41^{ab}	412.50 ± 13.38^{a}	25.59 ± 1.37^{a}
90°C	260.048 ±5.42^{f}	1220.42 ± 38.94^{bc}	69.92 ± 17.77^{c}	4.67 ± 1.08^{c}
100W	288.11 ±.5.54^{e}	1145.58 ± 102.09^{c}	77.41 ± 4.39^{c}	5.41 ± 1.00^{c}
300W	316.17 ±5.46^{d}	825.46 ± 85.90^{d}	362.61 ± 62.86^{a}	32.73 ± 7.50^{a}
500W	344.23 ±5.49^{c}	1459.47 ± 54.14^{a}	252.02 ± 8.19^{b}	14.01 ± 0.79^{b}

mol, mole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

Natural drying has the lowest bioavailability, followed by frozen fresh fruit sample. From the tables, it can be concluded that the total antioxidant capacity values by ABTS and DPPH method are identical to one another, showing similar results, while CUPRAC provided higher values for TAC, thus making it a more suitable method to be used for antioxidant estimation.

Cosmulescu et al. 2019, found that within the various genotypes of CC, the antioxidant capacity is between the range of 1.24 and 2.71 mmol Trolox $100g^{-1}$, from the DPPH method. According to this study, there is a significant difference in the antioxidant capacity shown by CC in different conditions, and using different methods also influences the analysis outcomes. Gunduz et al. 2013, investigated the antioxidant capacity of CC at different ripening stages using the ABTS method and found it to be in the range of 7.8 and 55.3 µmol Trolox g^{-1} fw. Moldovan et al. 2016, investigated fresh CC for antioxidant capacity using the ABTS and the FRAP assay. The study found the TAC of CC to be around 677.88 µmol Trolox 100 g^{-1} fw. These readings are higher than our results. Tural and Koca 2008, performed DPPH antioxidant assay to determine the antioxidant capacity of fresh CC fruit and found the result to be quite high (0.29–0.69 mg mL^{-1}) compared to the results from other studies, thus declaring the results to be

insignificant. Hassanpour et al. 2011, stated that within the different genotypes of CC, the %TAC is between the range of 39% and 82%, which implies that CC shows a very high antioxidant capacity, and indeed is vital in nutritional benefits. Horuz et al. 2017, estimated that the % inhibition of antioxidant activity in sour cherries using the radical scavenging assay (DPPH). The antioxidant activity of fresh sour cherry was about 48%, and that of convectional dried cherries was found to be between 12% to 33%, which is low than the fresh sample. High temperatures and extended drying times lead to the loss of phenolic compounds, thus reducing the antioxidant capacity. The TAC of hybrid dried sour cherries varied between 22.51% and 33.23%, which is higher than convectional drying. Horeckci et al. 2018, compared the antioxidant capacity of fresh CC with that of convective dried CC and found it to be 16.86 µg mL^{-1} for fresh fruit sample and between 37.74 to 49.47 µg mL^{-1}.

4.4.4. TAC of Blueberries (BB)

ABTS method

Table 4.9 (a), provides data on the TAC of BB. The measurements included in the table is according to the ascorbic acid content.

The highest antioxidant capacity for extractable phenols is found in 300 W, followed by natural drying and then 90°C; whereas, the lower antioxidant capacity is seen in 50°C. Likewise, for hydrolyzable phenols, the highest antioxidant capacity is found to be at 500 W along with 300 W; whereas, the lowest antioxidant capacity values are found in frozen fresh samples. According to the data from the table, the percentage bioavailability of both extractable and hydrolyzable is quite high for all the drying methods, suggesting that the phenols present in fresh and dried BB can efficiently be utilized for their antioxidant properties. This result is highly significant as it holds the potential of BB to be used as a natural preservative as well as the natural anticancer and antitumor agent.

Table 4.9 (a) Trolox equivalent antioxidant capacity (TEAC) for blueberries (BB) using the ABTS method

Drying Methods	Total Antioxidant Capacity (µmol Trolox 100g^{-1} fw)**			
	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	93.61 ± 2.13^{e}	8.87 ± 0.47^{g}	79.42 ± 0.60^{h}	77.62 ± 2.45^{e}
Natural drying	130.05 ± 3.82^{a}	20.40 ± 0.47^{e}	122.57 ± 0.20^{c}	81.56 ± 1.94^{d}
50°C	91.54 ± 0.36^{e}	30.56 ± 0.45^{c}	92.52 ± 0.69^{g}	79.73 ± 0.93^{e}
70°C	103.16 ± 1.21^{d}	15.63 ± 0.34^{f}	106.51 ± 1.23^{f}	89.69 ± 1.51^{c}
90°C	125.23 ± 0.84^{b}	20.95 ± 0.36^{e}	144.83 ± 0.77^{b}	99.10 ± 1.28^{b}
100W	123.55 ± 0.91^{b}	27.83 ± 0.38^{d}	161.82 ± 0.48^{h}	53.45± 0.54^{g}
300W	131.53 ± 0.71^{a}	50.07 ± 0.95^{b}	152.81 ± 0.20^{a}	84.15 ± 0.33^{d}
500W	107.99 ± 0.74^{c}	54.89 ± 0.52^{a}	144.33 ± 0.85^{b}	88.62 ± 0.78^{c}

µmol, micromole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

DPPH method

It is clear from the data provided in Table 4.9(b) that for the extractable phenols, the highest antioxidant capacity is at 300 W along with natural drying. It can also be seen that the values for frozen fresh fruit sample and that of 50°C are the same, while 100 W has the lowest antioxidant capacity for extractable phenols. Moreover, the antioxidant capacity in the hydrolyzable phenols is highest for natural drying, followed by 300 W and 70°C. The readings at 500W show the least antioxidant capacity. However, the bioavailability values are not as high as that in the ABTS method. The highest value is at 100 W, with approximately 57% bioaccessibility. Dried BB at 50°C has the lowest bioaccessibility for both the phenols.

Table 4.9 (b). Trolox equivalent antioxidant capacity (TEAC) for blueberries (BB) using the DPPH method

Drying Methods	Total Antioxidant Capacity (μmol Trolox 100g^{-1} fw)**			
	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	29.01 ± 0.06^{c}	28.65 ± 0.13^{de}	7.72 ± 0.26^{f}	13.39 ± 0.46^{e}
Natural drying	30.02 ± 0.75^{b}	32.59 ± 0.23^{a}	11.04 ± 0.34^{d}	17.64 ± 0.64^{d}
50°C	29.01 ± 0.25^{c}	28.00 ± 0.16^{e}	2.92 ± 0.34^{h}	5.12 ± 0.59
70°C	20.03 ± 0.19^{f}	30.24 ± 0.47^{bc}	13.02 ± 0.22^{c}	25.93 ± 0.75^{c}
90°C	16.67 ± 0.23^{g}	29.37 ± 0.19^{cd}	13.33 ± 0.44^{c}	28.96 ± 0.99^{b}
100W	12.81 ± 0.43^{h}	29.46 ± 0.38^{cd}	48.20 ± 031^{a}	57.04 ± 0.70^{a}
300W	32.48 ± 0.13^{a}	31.07 ± 0.51^{b}	6.48 ± 0.34^{g}	10.19 ± 0.50^{f}
500W	24.54 ± 0.25^{d}	26.81 ± 0.38^{f}	15.01 ± 0.40^{b}	29.23 ± 0.71^{b}

μmol, micromole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

CUPRAC method

As seen from Table 4.9 (c), the highest antioxidant capacity for extractable phenols is found in 100W, followed by 300 W and natural drying; and the lowest antioxidant capacity is at 50°C. Similarily, 100 W have the highest antioxidant capacity for hydrolyzable phenols, and frozen fresh fruit samples show the least value. In comparison with the bioavailability percentages of the ABTS and the DPPH methods, CUPRAC depicts higher results, with most bioavailability present in frozen fresh fruit samples and the least in 70°C.

Table 4.9 (c). Trolox equivalent antioxidant capacity (TEAC) for blueberries (BB) using the CUPRAC method

Drying	Total Antioxidant Capacity (mol Trolox/g fw)**			
Methods	E (Extractable)	H (Hydrolyzible)	B (Bioaccessible)	TB%
Frozen Fresh	147.92 ± 2.68^{h}	49.89 ± 1.78^{h}	274.16 ± 8.65^{bcd}	138.70 ± 5.60^{a}
Natural drying	666.33 ± 8.04^{b}	152.22 ± 2.61^{f}	225.23 ± 4.64^{e}	27.65 ± 0.84^{de}
50°C	337.33 ± 1.48^{f}	236.83 ± 3.24^{c}	198.60 ± 1.13^{fg}	34.59 ± 0.34^{c}
70°C	499.26 ± 13.10^{e}	193.45 ± 2.27^{d}	180.56 ± 3.00^{g}	26.08 ± 0.38^{e}
90°C	619.95 ± 1.87^{c}	164.24 ± 1.13^{ef}	260.02 ± 1.96^{d}	33.16 ± 0.22^{cd}
100W	1739.85 ± 6.60^{a}	1085.66 ± 20.43^{a}	1537.60 ± 13.90^{a}	54.42 ± 0.12^{b}
300W	681.80 ± 14.97^{d}	178.85 ± 2.23^{de}	282.79 ± 3.66^{bc}	32.89 ± 0.93^{cd}
500W	583.87 ± 7.07^{c}	291.38 ± 1.54^{b}	291.38 ± 1.71^{b}	33.29 ± 0.11^{c}

mol, mole; g, gram; fw, fresh weight; TB%, percentage bioavailability of phenols

**p<0.01 Column mean values with superscripts are significantly different;±SE, standard error

Furthermore, amongst all the three methods used to estimate the antioxidant capacity of the blueberries, CUPRAC has shown the highest values, which suggests that CUPRAC is the best suitable method for antioxidant analysis in blueberries. Moreover, between CC and BB, the higher antioxidant capacity values are shown by CC, while bioavailability of phenols is the highest for BB.

López et al. 2010, performed a study on fresh and convective dried blueberries. After application of different temperature using various drying processes, it was found that with increased air temperature, TAC also showed an increment rather than being decreased. The reason for this conclusion is justified by the fact that at lower temperatures, the long drying periods leads to the oxidation of phenolic compounds, leading to the reduced antioxidant capacity. Kalt et al. 1999 (a), studied various small fruits along with blueberries for their antioxidant and total phenolic content. The study revealed that the antioxidant capacity of blueberries to be in the range of 60-64 µmol Trolox. g $^{-1}$ fw. These values are comparable to our findings. Kraujalyte et al. 2015, this study provides data on the antioxidant capacity of different varieties of BB and found

TAC in the range of 6-20 µmol Trolox. g $^{-1}$, using the ABTS method. These are in a similarity to our study.

Table 4.10 shows the positive and negative correlations between the drying period, color parameters, total phenolic content, total antioxidant capacity, total ascorbic acid, and total anthocyanin of CC. The values marked in red color denotes positive relations while the values marked in blue color denotes negative relations. According to the data from the table, there is 92.24%, 95.06%, and 92.98% positive correlation of the *L* coordinate with *a, b,* and *C* color coordinates, respectively. Similarly, coordinate *a* has a 98.51% and 99.96% positive correlation with coordinates *b* and *C*, respectively. Also, a positive 98.98% relation was seen between coordinate *b* and *C*.

Similarly, there is a negative correlation between the extractable TAC measurements for ABTS, DPPH, and CUPRAC and the color coordinates *L, a, b,* and *C* with values as follows- 80.67%, 77.68%, 75.04%, and 77.45% ; and 80.87%, 77.46%, 75.69%, and 77.36%; and 86.72%, 81.99%, 80.13%, and 81.97%, respectively. A positive 98.79% and 88.35% correlation is found between the extractable TAC measurements of ABTS with that of DPPH and CUPRA, respectively; moreover, a 99.75% positive relation between hydrolyzable phenols of DPPH with ABTS can be seen. Between the extractable CUPRAC and DPPH, there is a 90.33% positive relation. There is a negative 76.48% the bioaccessible phenols of ABTS with that of hydrolyzable phenols. An 88.87% and 87.66% negative relation can be seen between the bioaccessible phenols with hydrolyzable ABTS and DPPH, respectively. Furthermore, 98.41% and 75.19% positive relation was found between bioaccessible ABTS with DPPH and bioaccessible phenol with DPPH, respectively. Besides, there is a negative 78.15% and 75.34% correlation of hydrolyzable phenol with that of bioaccessible phenols and between hydrolyzable phenol and bioaccessible DPPH.

Table 4.10 Correlation matrix for drying period, color parameters, TPC, TAC, TAA, TA in cornelian cherry (CC)

	L	a	b	c	α	TA	AA	DP	ABTS E	ABTS H	ABTS TB%	DPPH E	DPPH H	DPPH TB%	CUPRAC E	CUPRAC H	CUPRAC TB%	TPC E	TPC H	TPC TB%
L	1,0000	0,9224	0,9506	0,9298	-0,0378	0,0444	0,4685	0,3421	-0,8067	0,5243	-0,1817	-0,8087	0,5218	-0,2183	-0,8672	0,4312	-0,0698	-0,4431	0,4825	-0,6326
a		1,0000	0,9851	0,9996	-0,2901	-0,1133	0,5418	0,3884	-0,7768	0,6751	-0,1201	-0,7746	0,6737	-0,1630	-0,8199	0,4002	0,1197	-0,2539	0,3519	-0,6889
b			1,0000	0,9898	-0,1684	-0,0530	0,5184	0,3308	-0,7504	0,6472	-0,1405	-0,7569	0,6459	-0,1728	-0,8013	0,3797	0,1246	-0,2666	0,4172	-0,6826
c				1,0000	-0,2679	-0,1044	0,5386	0,3806	-0,7745	0,6720	-0,1255	-0,7736	0,6705	-0,1669	-0,8196	0,3987	0,1198	-0,2575	0,3650	-0,6900
α					1,0000	0,0396	-0,4487	-0,2123	0,3739	-0,1636	-0,2950	0,3710	-0,1812	-0,2714	0,1852	-0,1479	0,1539	0,0890	0,4575	0,0048
TA						1,0000	-0,1082	-0,1516	-0,2507	-0,1360	-0,1267	-0,2927	-0,1341	-0,0890	-0,1553	0,3631	-0,5339	-0,3539	0,1603	0,0401
AA							1,0000	-0,0957	-0,4806	0,3815	0,0898	-0,4616	0,3876	0,0472	-0,4015	0,3548	-0,0937	-0,1297	-0,0606	-0,2082
DP								1,0000	-0,4443	-0,1046	0,1279	-0,4399	-0,1175	0,0735	-0,5256	-0,0031	-0,2236	-0,5426	-0,1342	-0,0531
ABTS E									1,0000	-0,3599	0,0301	0,9879	-0,3525	0,0861	0,8835	-0,5426	0,4342	0,6590	-0,1579	0,3944
ABTS H										1,0000	-0,5497	-0,3374	0,9975	-0,5871	-0,4381	0,6411	0,3602	0,3982	0,5073	-0,8887
ABTS TB%											1,0000	0,0522	-0,5324	0,9841	0,3097	-0,5624	0,1063	-0,1677	-0,7648	0,7422
DPPH E												1,0000	-0,3314	0,0848	0,9033	-0,5236	0,4548	0,6850	-0,1647	0,3989
DPPH H													1,0000	-0,5715	-0,4267	0,6306	0,3607	0,4103	0,4890	-0,8766
DPPH TB%														1,0000	0,3393	-0,5976	0,1160	-0,1613	-0,7534	0,7519
CUPRAC E															1,0000	-0,5368	0,3607	0,6212	-0,4163	0,6092
CUPRAC H																1,0000	-0,3504	-0,0499	0,3462	-0,6058
CUPRAC TB%																	1,0000	0,7391	0,1118	-0,2168
TPC E																		1,0000	0,0120	-0,1578
TPC H																			1,0000	-0,7815
TPC TB%																				1,0000

E, extractable; H, Hydrolyzable; TB%, percentage bioaccessibility; TPC, total phenolic content; L, brightness; a, redness/greeness; b, yellowness/blueness; C, chroma; α, hue angle; AA, ascorbic acid; TA, total anthocyanin; DP, drying period;
ABTS, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); DPPH, 2,2-diphenyl-1-picrylhydrazyl; CUPRAC, cupric reducing antioxidant capacity.

Table 4.11 shows the positive and negative correlations between the drying period, color parameters, total phenolic content, total antioxidant capacity, total ascorbic acid, and total anthocyanin of BB. The values marked in red color denotes positive relations while the values marked in blue color denotes negative relations. From the table, a 78.70% positive relation is seen between the extractable phenolics with that of extractable CUPRAC; and an 83.91% positive relation between extractable CUPRAC with ABTS. There is an 86.04% positive relation between bioaccessible phenols from DPPH with that of ABTS.

Furthermore, 73.08% and an 80.91% negative relation can be seen between bioaccessible CUPRAC with that of the hydrolyzable phenolics and extractable CUPRAC. Between the color coordinate *C* and *a*, 79.05% positive relation is seen, while between coordinate α and *b*, there is an 87.10% negative correlation. There is a positive 71.47% and 74.18% correlation between total anthocyanin with bioaccessible DPPH and ABTS, respectively. Furthermore, a negative 75.64% relation between bioaccessible CUPRAC and hydrolyzable CUPRAC.

Table 4.11 Correlation matrix for drying period, color parameters, TPC, TAC, TAA, TA in blueberries (BB)

	TPC E	TPC H	TPC TB%	ABTS E	ABTS H	ABTS TB%	DPPH E	DPPH H	DPPH TB%	CUPRAC E	CUPRAC H	CUPRAC TB%	L	a	b	C	α	TA	AA	DP
TPC E	1,0000	0,1608	-0,5880	0,6121	0,4760	0,5082	-0,0655	0,3947	0,2076	0,7870	0,2783	-0,6749	0,0135	-0,0639	0,1088	-0,1612	-0,0888	0,5965	-0,1562	-0,3631
TPC H		1,0000	0,1748	0,2351	0,0714	-0,0507	-0,0338	0,4014	0,0670	0,5016	0,4914	-0,7308	0,0655	-0,0537	-0,0521	-0,0795	0,0375	-0,0097	-0,3622	-0,1770
TPC TB%			1,0000	0,0998	0,0976	-0,4162	0,0367	-0,1645	-0,0702	-0,0240	0,1629	0,1701	0,0170	0,1944	-0,0906	0,3012	0,0269	-0,1405	-0,0345	0,0538
ABTS E				1,0000	0,2960	0,0575	-0,1126	0,5540	-0,0070	0,8391	0,1664	-0,4783	-0,0251	0,2186	0,0020	0,2813	-0,0520	0,3637	-0,0554	-0,3714
ABTS H					1,0000	0,0114	0,1933	-0,2723	-0,0552	0,5087	0,7099	-0,4744	0,0141	0,0222	0,0850	-0,0937	-0,0859	0,4115	-0,5350	-0,4601
ABTS TB%						1,0000	-0,4523	0,0860	0,8604	0,3602	-0,0363	-0,2631	0,0422	-0,2420	0,1310	-0,3243	-0,0822	0,7418	0,4416	0,0916
DPPh E							1,0000	0,2375	-0,4937	-0,1887	-0,2803	0,2827	0,1613	-0,0051	0,0049	0,0152	0,0149	-0,0491	-0,6242	-0,0870
DPPh H								1,0000	0,0337	0,4635	-0,3658	-0,2405	0,1188	0,0251	-0,0209	0,0790	0,0129	0,1573	-0,0686	0,0721
DPPH TB%									1,0000	0,2720	-0,0254	-0,1467	0,0645	-0,2365	0,0961	-0,2921	-0,0647	0,7147	0,4742	0,1475
CUPRAC E										1,0000	0,4728	-0,8091	0,0286	0,0455	0,0490	0,0095	-0,0723	0,5746	-0,1664	-0,4066
CUPRAC H											1,0000	-0,7564	-0,0723	0,0148	0,0116	-0,1041	-0,0303	0,0567	-0,3845	-0,3992
CUPRAC TB%												1,0000	0,0049	0,0493	-0,0264	0,1553	0,0342	-0,2618	0,2963	0,3612
L													1,0000	-0,2333	-0,5476	-0,3540	0,4731	0,1043	-0,0548	0,0309
a														1,0000	0,2518	0,7905	-0,0868	-0,1461	-0,0336	-0,0781
b															1,0000	0,3011	-0,8710	0,1411	0,0023	-0,0415
C																1,0000	-0,3662	-0,1906	0,0281	-0,0528
α																	1,0000	-0,1139	-0,0096	0,0400
TA																		1,0000	0,0361	-0,2144
AA																			1,0000	0,1943
DP																				1,0000

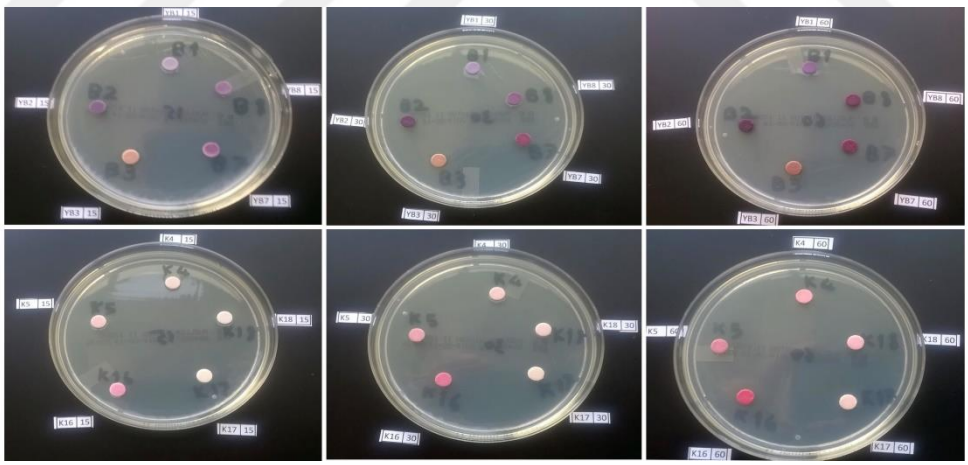
E, extractable; H, Hydrolyzable; TB%, percentage bioaccessibility; TPC, total phenolic content; L, brightness; a, redness/greeness; b, yellowness/blueness; C, chroma; α, hue angle; AA, ascorbic acid; TA, total anthocyanin; DP, drying period;
ABTS, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); DPPH, 2,2-diphenyl-1-picrylhydrazyl; CUPRAC, cupric reducing antioxidant capacity

4.5. Antimicrobial activity

The polyphenols and flavonoids present in the plants are said to have antimicrobial activity. Since the past few years, many such research studies are being conducted to investigate the biochemical composition of phenol rich fruits. These studies are carried out in order to find natural bioactive compounds that can replace the chemical preservatives and can also be used as health boosters and nutritive agents, which have antimicrobial and anticancer properties, in order to prevent the resistance against synthetic antibiotics.

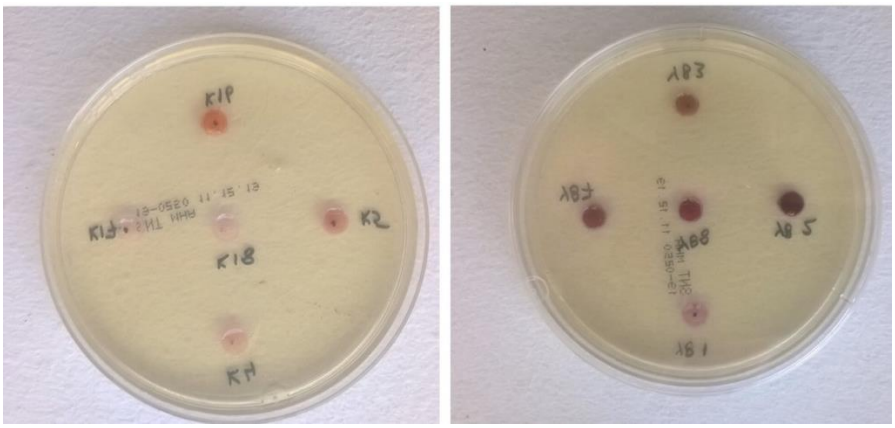
Our study was also conducted to test for the antimicrobial activity of cornelian cherry and blueberry, as both these fruits contain high polyphenols and show high antioxidant activity. During the study, the methanolic extracts of frozen fresh and dried cornelian cherry and blueberries were tested against *E.coli* for its antimicrobial activity. Two different fruit extracts were applied to check the antimicrobial activity.

a b c



d e f

Figure 4.5. MH-agar plates disc diffusion treatment against *E. coli*. **(a)** BB at 15 µL, **(b)** BB at 30 µL, **(c)** BB at 60 µL, **(d)** CC at 15 µL, **(e)** CC at 30 µL, and **(f)** CC at 60 µL



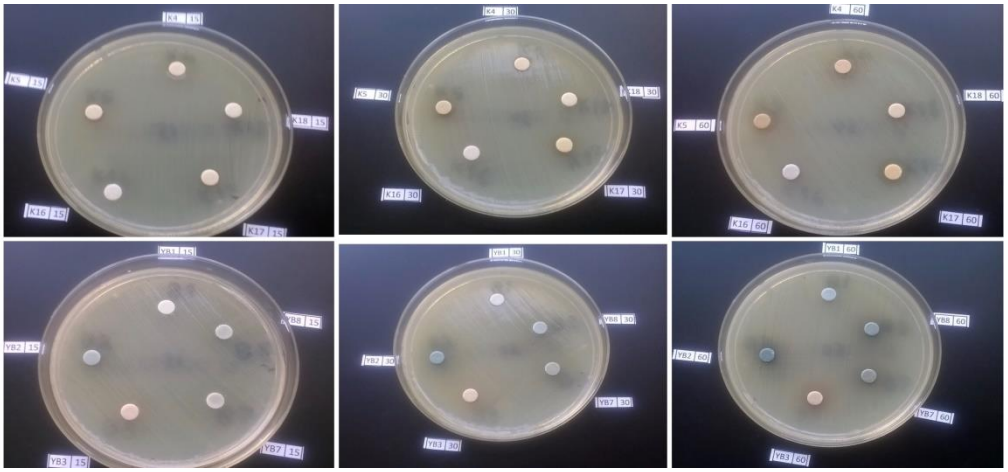
a b

Figure 4.6. MH-agar plates with microwell diffusion method
(a) CC extraction solution **(b)** BB extraction solution

Figure 4.5 depicts different dosages of fruit extracts used to test the antimicrobial by disc diffusion method. The figure clearly shows the diffusion of the fruit extracts within the agar medium inoculated with *E. coli* bacterial strains. Similarly, Figure 4.6 contains pictures of agar plates with *E. coli* bacterial strains using microwell diffusion method.

As a result of the analysis, no bactericidal effect was detected for both the fruit samples against *E.coli*. The negative result can be attributed to many factors. Due to prolonged heat treatments reduction in the moisture content of the fruits may have led to the loss of polyphenols. The poor solubility of phenols and high sensitivity to heat and pH may be the cause of negative antimicrobial activity.

a b c

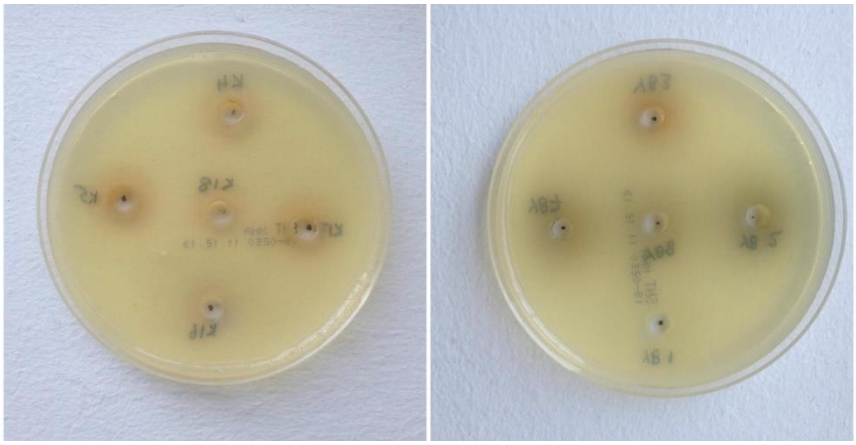


d e f

Figure. 4.7. Agar disk diffusion test results against E.*coli*. **(a)** 15 µL CC extract solution **(b)** 30 µL CC extract solution **(c)** 60 µL CC extract solution **(d)** 15 µL BB extract solution **(e)** 30 µL BB extract solution **(f)** 60 µL BB extract solution

Figure 4.7 shows the results after the petri dishes were incubated with fruit extract solutions with different concentrations against E.*coli* bacteria. From the figure, it is seen that there has not been an inhibition zone formed around the microdisks, thus referring to no antimicrobial activity.

Lacombe et al. 2013, performed the antimicrobial activity against many different bacterial strains for blueberries. The study found that the *E.coli* O157: H7 strain showed susceptibility against blueberry extract solution, which is contradictory to our results. Calliet et al. 2012, tested cranberry juice and fruit extract for their antimicrobial activity against *E.coli* and *S.aureus*. The study concluded that *E.coli* showed least to no susceptibility against the fruit extract, which can be comparable to our results. Turker et al. 2012, tested various wild fruits for antimicrobial activity and determined that using different fruit extract solutions (water and ethanol), against different bacteria does not produce any inhibition zone after incubation for 2 days. These results are identical to our finding.



(a) (b)

Figure 4.8. Microwell diffusion test results against E.*coli* **(a)** CC extraction solution with no inhibition zone and **(b)** BB extraction solution with no inhibition zone

In Figure 4.8, the results for microwell diffusion method against *E. coli* can be seen. The figure clearly shows that for different concentrations of both CC and BB fruit extracts, no microbial activity was observed.

5. CONCLUSION

In this thesis study, different drying methods were applied to two types of fruit, that is, cornelian cherry CC (*Cornus mas* L.) and blueberry BB (*Vaccinium* spp.). During the research work, both CC and BB were exposed to natural drying, convective drying at (50°C, 70°C, and 90°C), microwave drying at (100 W, 300 W, and 500 W) power outputs, and the combined microwave-convective drying at (100 W-50°C, 100 W-70°C, 100W-90°C, 300 W-50°C, 300W-70°C, 300W-90°C, 500W-50°C, 500W-70°C, and 500W-90°C).

The initial moisture content of cornelian cherry (CC) at 72.56 ±0.18% was reduced down to 10.27 ± 0.13%; whereas the moisture content of blueberries (BB) initially at 84.76 ± 0.20% was reduced to 10.03 ± 0.09%. For cornelian cherry the natural drying period lasted up to 29 days, convective drying between (260 and 3060 min); while microwave drying lasted between (50 and 153 min). The combined microwave-convective drying lasted from (30 to 150 min). Similarly, for blueberries natural drying lasted for 22 days, convective drying for (340 to 3540 min). The microwave drying and combined drying for BB lasted between (64 and 198 min), and (18 and 160 min), respectively. The most extended drying period was estimated to be for convective drying at 50°C for both the fruit samples and the shortest time was found for combined microwave-convective drying at 500W-90°C. The specific energy consumption values were highest for 50°C and lowest for 100 W in both the samples.

The fresh and the dried samples of CC and BB were tested for different quality parameters such as color change, total anthocyanins (TA), ascorbic acid content (AAC), total phenolic content (TPC), total antioxidant capacity (TAC), and antimicrobial activity.

In terms of color parameters, the best results for CC and BB were found to be for frozen fresh samples. The total anthocyanin in CC has the highest value at 70°C, after frozen fresh samples; while for BB 300W shows the highest values. In regards to ascorbic acid values, for CC natural drying shows the most compatible results after frozen fresh

samples, whereas, for BB, 500 W has a higher value compared to other dosages. The total phenolic content of CC in accordance with extractable and hydrolyzable phenols is highest for frozen fesh samples, while in reference to bioavailability 100 W showed highest value. Furthermore, for BB 300 W has the best results for TPC.

For determining the total antioxidant capacity of phenolic compounds present within cornelian cherries and blueberries, three different types of methods were employed namely ABTS, DPPH, and CUPRAC. From the study, it was summarized that cornelian cherry shows higher antioxidant capacity than blueberries. However, the phenolic compounds present in blueberries show significantly higher bioavailability (up to 90%), compared to that for CC. It was also concluded that CUPRAC is the most suitable method for estimation of antioxidant capacity of both CC and BB.

In terms of antimicrobial activity, both the fruits did not possess any antimicrobial activity againt *E.coli* in our study.

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