REVIEW ARTICLE

Nutrition, Metabolism, and Prevention of NCDs

The Impact of Black Chokeberry (*Aronia melanocarpa*) on Gut Microbiota and Human Health: Systematic Review and Meta-analysis of Randomized Controlled Trials in Humans

Berrak Basturk [1] ✉ **Zeynep Koc Ozerson** [1] **Aysu Yildiz Karaahmet** [2] **Kardelen Busra Ege Gunduz** [1] **Sumeyye Bora** [1]

1 Halic University, Faculty of Health Sciences, Nutrition and Dietetics, 15 July Martyrs Street, No: 14/12, Eyupsultan, Istanbul, Türkiye. berrakerguden@halic.edu.tr / zeynepkoc@halic.edu.tr / kardelenegegunduz@halic.edu.tr / sumeyyebora@halic.edu.tr

2 Biruni University, Faculty of Health Sciences, Department of Midwifery, Merkezefendi, 75 Sk No:1-13 M.G, 34015 Zeytinburnu, Istanbul, Türkiye. aysuyildizz@hotmail.com

ABSTRACT

Background: *Aronia melanocarpa*, commonly known as chokeberry, is a fruit experiencing increasing cultivation and recognition due to its health-promoting properties. Its primary bioactive components are (poly)phenols, which are recognized for their crucial role in modulating the intestinal microbiota and exerting beneficial effects on human health.

Aims: This study aimed to systematically synthesize and critically evaluate the findings of randomized clinical trials investigating the impact of *Aronia melanocarpa* consumption on the modulation of gut microbiota composition and its metabolism-mediated physiological consequences in human subjects.

Methods: Randomized controlled trials published in English were considered for inclusion. Comprehensive searches were conducted across the Cochrane Library, Scopus, PubMed/MEDLINE, and Web of Science databases up to October 20, 2024. A systematic evaluation of gut microbiota parameters was performed. For secondary metabolite levels, biochemical markers, and cardiovascular risk parameters, a meta-analysis utilizing a mean effect model was conducted.

Results: Four articles, collectively involving 200 participants, met the inclusion criteria for this systematic review. Of these, three articles were subsequently incorporated into the meta-analysis**.** Consumption of *Aronia melanocarpa* intervention periods ranging from 4 to12 weeks did not yield significant differences in the α-diversity or β-diversity of the gut microbiota. However, increased levels of specific bacterial genera and species, including *Intestinimonas butyriciproducens, Lawsonibacter asaccharolyticus*, *Bacteroides xylanisolvens*, *Bacteroides, Anaerostipes, Butyricimonas faecihominis,* were observed in individuals consuming Aronia capsules for 12 weeks. Furthermore, *Aronia melanocarpa* consumption significantly increased non-flavonoid polyphenol stilbenes by a mean difference of 0.11 (95% CI: 0.03, 0.20, p = 0.010) compared to control groups. No significant differences were detected in vascular function or fasting plasma glucose levels.

Conclusions: The included studies indicate that *Aronia melanocarpa* exerts positive effects on the gut microbiota. Notably, interventions involving *Aronia melanocarpa* consumption for 12 weeks and those with high polyphenol content appeared to be more effective in modulating the microbiota. However, no statistically significant beneficial impact on broader health parameters was identified in this meta-analysis. This outcome is likely attributable to variations in dosage, product type, intervention durations, participant characteristics, and the specific final measurements employed across the included studies.

Keywords: *Aronia melanocarpa*; Gut function; Gut symptoms; Meta-analysis; Microbiota; Systematic review.

ARTICLE INFORMATION

Check for updates

✉ **Corresponding author:** Berrak Basturk
E-mail: berrakerguden@halic.edu.tr / dyt.erguden@gmail.com
Tel. +90 5465088090

Received: March 27, 2025
Revised: April 14, 2025
Accepted: May 22, 2025
Published: July 07, 2025

Article edited by:
Prof. Diaf Mustapha
Article reviewed by:
Dr. Halima Boughellout
Dr. Sabiha Zeynep Aydenk Koseoglu

Cite this article as: Basturk B., Koc Ozerson Z., Yildiz Karaahmet A., Ege Gunduz K.B., Bora S. (2025). The Impact of Black Chokeberry (*Aronia melanocarpa*) on Gut Microbiota and Human Health: Systematic Review and Meta-analysis of Randomized Controlled Trials in Humans. *The North African Journal of Food and Nutrition Research, 9* (20): 1 – 15. https://doi.org/10.51745/najfnr.9.20.1-15

1 INTRODUCTION

In the early 20th century, an extensive scientific interest emerged in investigating foods rich in phytochemicals and evaluating their associated bioactivity. Among these, *Aronia melanocarpa* (Black chokeberry) has garnered substantial attention and is currently recognized as one of the most sought-after superfoods in Europe and globally (Gurčík *et al.*, 2023). *Aronia melanocarpa* particularly notable for being among the richest plant sources of polyphenols (Jurendić *et al.*, 2021). Its remarkably high concentration of bioactive compounds, ranging from 10 to 5500 mg per 100 g of dried fruit, includes various phenolic chemicals such as procyanidins, anthocyanins, and phenolic acids. Key bioactive constituents specifically identified are procyanidins, quercetin, chlorogenic acid, and cyanidin-3-O-galactoside (Ren *et al.*, 2022). Aronia berries are recognized as one of the richest dietary sources of anthocyanins, predominantly cyanidin-glycoside (Taheri *et al.*, 2013). The inherent anti-inflammatory properties of *Aronia melanocarpa* contribute to the prevention of chronic diseases such as diabetes mellitus

and cardiovascular conditions, while also offering protective effects on the immune system (Jurikova *et al.*, 2017). In addition, the (poly)phenols present in Aronia are increasingly acknowledged as regulators of the intestinal microbiome, promoting the proliferation of beneficial bacteria and enhancing microbial diversity within the gut (Le Sayec *et al.*, 2022). A significant proportion of ingested polyphenols reach the large intestine, where they undergo bacterial degradation into simpler phenolic metabolites. Both polyphenols and their metabolites positively exert positive effects on intestinal barrier integrity through their anti-inflammatory action. Concurrently, an increase in microbial diversity may favorably influence microbial bioavailability (Wilson *et al.*, 2023).

The gut microbiota, a complex ecosystem comprising trillions of microorganisms, plays a crucial role in fundamental physiological processes. These include the efficient digestion of macronutrients, the endogenous synthesis of essential of vitamins, and its function as a crucial endocrine organ, all collectively contributing to the maintenance of systemic homeostatic balance. Consequently, dysbiosis, or disruptions in the composition and equilibrium of the gut microbiota, may predispose individuals to the development of various chronic and autoimmune diseases, such as obesity and diabetes (Lotti *et al.*, 2023). The intricate composition and diversity of the gut microbiota profoundly influence gastrointestinal health (Creedon *et al.*, 2020). There is growing body of evidence highlighting the significant impact of gut microbiome on overall human health. Bacterial species belonging to genera *Lactobacillus* and *Bifidobacterium* are generally considered beneficial for human health. In contrast, an increase abundance of genera such as *Clostridium*, *Eubacterium*, and *Bacteroides* has been associated with adverse health outcomes (Nash *et al.*, 2018). Given this context, the present study systematically investigates the effects of *Aronia melanocarpa* consumption on the gut microbiota and other relevant health indicators in humans. This investigation is primarily conducted through a comprehensive systematic review and meta-analysis of placebo-controlled randomized controlled trials (RCTs), with the exclusive selection of human studies aiming to accurately determine the outcomes of complex absorption and intermolecular interactions within the human physiological system.

2 METHODS

2.1 Study Design

This systematic review and meta-analysis aimed to investigate RCTs that assessed the impact of *Aronia melanocarpa* on bacterial colonization, fecal microbiota, gut microbiota composition, and associated human health indicators. The methodology adhered strictly to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The study's protocol was prospectively registered with the PROSPERO International Prospective Registration System for Systematic Reviews (http://www.crd.york.ac.uk/prospero; No. CRD42024593226). To mitigate potential bias throughout the evaluation process, two investigators independently conducted the literature review, article selection, data extraction, and quality assessment of the included studies to reduce the potential for bias throughout the evaluation process. Any discrepancies arising between the reviewers were resolved through collegial discussion, leading to a consensus decision.

2.2 Search Strategy

Two researchers from the investigate team (B.B and K.B.E.G) independently performed comprehensive and blinded searches across the Cochrane Library, PubMed/MEDLINE, Scopus, and Web of Science databases. The search was conducted up to 20 October 2024. Only RCTs published in English were considered for inclusion with no restrictions applied regarding the publication year during the database search. The following keywords and Boolean operators were utilized in the search strategy; *Aronia* "OR "*Photinia* "OR "*Aronia melanocarpa*" AND "gut function "OR "gut symptoms", OR "microbiome "OR "microbiota "OR "diversity"

2.3 Inclusion and Exclusion Criteria

The study considered RCTs that investigated the effects of *Aronia melanocarpa* on human gut microbiota, gut function, and broader health parameters. The PICOS (Patient/Population, Intervention, Comparison, and Outcomes) framework was systematically applied to define the research question and guide the selection process.

The inclusion criteria for the review were:

- Studies involving adult participants aged 18 years and older, encompassing both healthy individuals and those diagnosed with gastrointestinal diseases.
- Articles published in the English language.
- Studies reporting outcomes measuring at least one of the following: gut microbiota composition, density of certain gut bacteria, frequency of bowel symptoms, transit time, stool form.
- Studies reporting a quantitative or measurable dose and form of Aronia administered, with an intervention period of at least one week.

Studies were excluded based on the following criteria:

- *In vitro* studies, animal models, or artificial gastrointestinal models.
- Observational studies and case reports.

- Studies published in languages other than English
- Studies in which *Aronia melanocarpa* was administered in combination with other active substances.

2.4 Study Selection

Mendeley Reference Manager, reference management software, was used to review all citations and eliminate duplication across the four databases. Two (B.B and K.B.E.G) independently performed study selection and data extraction. To ascertain eligibility, researchers filtered papers according to predetermined inclusion and exclusion criteria, and they resolved any disagreements through group discussions. To guarantee the precision, reliability, and superior quality of the data, standardized and predetermined data extraction forms were used. The screening procedure and outcomes were recorded and reported using the PRISMA flowchart (Figure 1).

2.5 Data Extraction

Figure 1 provides a comprehensive overview of the study selection process. Following the screening, selection, and quality assessment of the identified studies, data were systematically extracted using a pre-designed form. Extracted data included the surname of the first author, year of publication, number of participants randomly assigned to the control and intervention groups, participant age, type and dose of Aronia, duration of treatment, measured outcomes, study design, and details of randomization. Overall, high inter-reviewer agreement was observed during article selection and data extraction. Minor discrepancies were resolved through re-evaluation of the data and subsequent collegial discussions. The characteristics of the included studies are presented in Table 1.

Risk of bias assessment

The risk of bias for each included study was assessed using the criteria outlined in the Cochrane Handbook for Systematic Reviews of Interventions. Two independent researchers (B.B. and A.Y.K.) independently assessed the risk of bias. In instances of disagreement, a joint re-evaluation of the respective study was undertaken to reach consensus on the risk of bias within each domain each domain. Given that all four included studies were randomized controlled trials (RCTs), the risk of bias was assessed across seven key domains: sequence generation, allocation concealment, blinding of participants and researchers, blinding of outcome assessment, insufficient outcome data, selective outcome reporting, and other potential threats to validity. The risk of bias for each domain was categorized as low, high, or unclear.

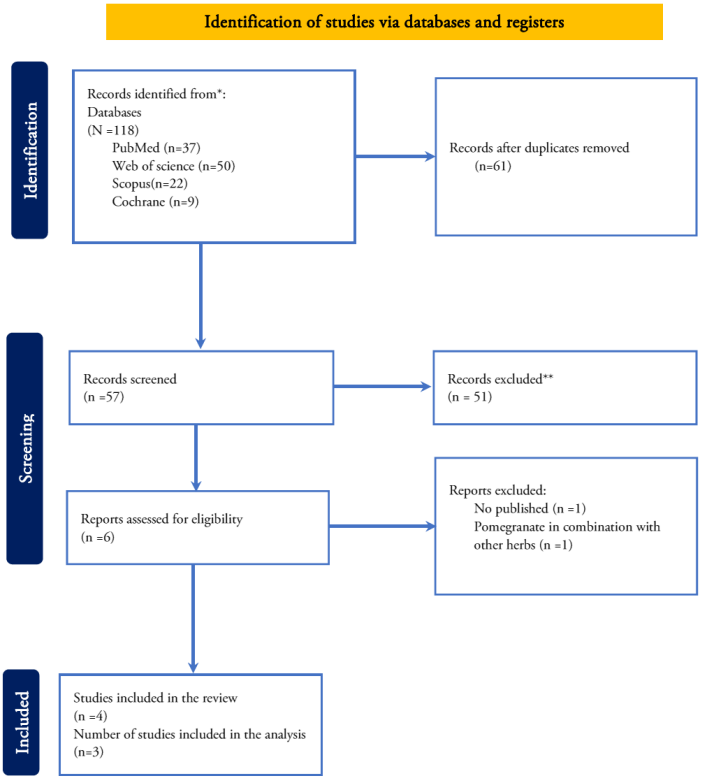

Figure 1. Flow diagram for systematic reviews (Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020)

Table 1. Characteristics of the participants of the included studies (n = 4)

Author, year (Country)	Study type	Groups (n)	Dosage	Mean age (X±SD)	Duration	Main results	Secondary Outcome
Le Sayec, *et al.*, 2022 (London)	RCT	Prehypertensive individuals Aronia capsule:42 Control:43	1 capsule (500 mg/day (105.9 mg polyphenols)	Aronia = 56.2 ± 8.7 Control = 56.2 ± 9	12 weeks	— α-diversity and β-diversity Microbial gene enrichment ↑ **Aronia capsules:** *Intestinimonas butyriciproducens, Lawsonibacter asaccharolyticus, Butyricimonas faecihominis*↑, Bacteroides *xylanisolvens*↑, *Senegalimassilia anaerobia*↓, *Haemophilus* ↓	**Vascular Function:** Peripheral AIx↓, Central AIx↓, PWV↓, BP NC **Urinary metabolite:** 1 benzoic acid derivative and 4 cinnamic acid derivatives ↑ **Plasma metabolite:** 6 cinnamic acid derivatives, 5 benzoic acid derivatives, and 1 phenyl propanoic acid derivatives ↑
Chamberlin *et al.*, 2024 (USA)	RCT	Healthy individuals Aronia juice:7 Placebo:7	100 ml/day (total polyphenols not specified, polyphenolic compounds given in quantity)	Aronia = 35.0 ± 7.8 Control = 32.4 ±7.0	30 days	— Microbial evenness and β-diversity Average microbial richness↓ **Aronia juice:** *Holdemania* and *Barnesiella* abundance ↓* *Oxalobacteraceae, Prevotellaceae* and *Pasturellaceae* ↑ * After multiple tests correction NC	**Biochemical parameters:** Cholesterol levels↓ Postprandial glucose↓ **Serum metabolite:** Asparagine↑ Tyrosine↑ **Fecal metabolite:** Kenodeoxycholic acid ↑
Istas *et al.*, 2019 (London)	RCT	Healthy individuals Aronia capsule (116 mg (poly)phenols): 23 Aronia whole fruit capsule: 23 Control:20	1 capsule (500 mg /day (respectively 116 mg;12 mg polyphenols)	Aronia capsule = 24 ± 6.3 Aronia whole fruit capsule = 24 ± 5.2 Control = 23 ± 4.4	12 weeks	Microbial diversity was very high but NC. **Aronia whole fruit:** *Bacteroides* ↑ (+193%) **Aronia extract:** *Anaerostipes* ↑ (+10.6%) **Placebo**: *Clostridium* XiVb↑	**Vascular Function:** Aronia whole fruit vs. control: FMD (%) ↑ (+0.9) **Aronia extract vs. control:** FMD (%) ↑ (+1.2) **Plasma Metabolite:** Aronia whole fruit: 10 phenolic metabolites↑ **Aronia extract:** 18 phenolic metabolites↑ **Placebo:** 4 phenolic metabolites↑

Table 1. (Continued)

Author, year (Country)	Study type	Groups (n)	Dosage	Mean age (X±SD)	Duration	Main results	Secondary Outcome
Lackner *et al.*, 2024 (Australia)	RCT	Healthy individuals Aronia juice: 17 Placebo:18	200 mL/day (1666 mg polyphenol)	Aronia = 26.6 ± 4.9 Control = 24.6± 4.3	12 weeks (time point(tp)1: Baseline, tp2: 6 weeks intervention 3:6-week wash-out)	**Aronia juice:** α-diversity ↑ *Anaerostipes*-associated ribosomal sequence variants tp 1:2↑*, tp 1:3↑*, tp 2:3 NC *Bacteroides* tp 1:2 NC, tp 1:3↑*, tp 2:3↑* *Ruminococcus* tp 1:2↑*, *Eubacterium coprostanoligenes,* tp 1:3↑*, Lachnospiraceae UCG-004 tp 1:3↑*, *Odoribacter* tp 2:3↑* **Aronia vs. control:** The diversity indices (Shannon index, richness, and evenness) NC * After statistical multiple testing NC.	**Biochemical parameters:** Over 30 parameters associated with lipoprotein metabolism↑ (ABA1, H3A2, IDAB, IDCH, IDFC, IDPL, IDPN, L4AB, L4CH, L4FC, L4PL, L4PN, L4TG, L5AB, L5CH, L5FC, L5PL, L5PN, LDHD, TBPN, TPAB, V3CH, V3FC, V3PL, V3TG, V4CH, V4FC, V4PL, V4TG, VLAB, VLCH, VLPN)

Note: NC: There were no statistically significant changes from the beginning of the intervention to its conclusion; **ABA1**, Apo-B100/Apo-A1 ratio; **AIx**, augmentation index; **BP**, blood pressure; **FMD**, flow-mediated; **H3A2**, HDL-3 Apo-A2;**IDL,**intermediate density lipoprotein; **IDAB**, IDL Apo-B100; **IDCH**, IDL cholesterol; **IDFC**, IDL free cholesterol; **IDPL**, IDL phospholipids; **IDPN**, IDL particle number; **LDL,**Low Density Lipoprotein; **L4AB**, LDL-4 Apo-B100; **L4CH**, LDL-4 cholesterol; **L4FC**, LDL-4 free cholesterol; **L4PL**, LDL-4 phospholipids; **L4PN**, LDL-4-particle number; **L4TG**, LDL-4 triglycerides; **L5AB**, LDL-5 Apo-B100; **L5CH**, LDL-5-cholesterol; **L5FC**, LDL-5 free cholesterol; **L5PL**, LDL-5 phospholipids; **L5PN**, LDL-5 particle number; **LDHD**, LDL-cholesterol/ HDL-cholesterol ratio; **PWV**, pulse wave velocity; **TBPN**, total particle number; **TPAB**, total Apo-B100;**VLDL,**Very Low Density Lipoprotein; **V3CH**,VLDL-3 cholesterol;**V3FC**, VLDL-3 free cholesterol; **V3PL**, VLDL-3 phospholipids; **V3TG**, VLDL-3 triglycerides; **V4CH**, VLDL-4 cholesterol; **V4FC**, VLDL-4 free cholesterol; **V4PL**, VLDL-4 phospholipids; **V4TG**, VLDL-4 triglycerides; **VLAB**, VLDL Apo-B100; **VLCH**, VLDL cholesterol; **VLPN**, VLDL particle numb

2.6 Statistical Analysis

Meta-analysis was performed for outcomes reported by two or more studies. Data were entered into Review Manager software (RevMan, version 5.3; The Cochrane Collaboration, Copenhagen, Denmark) for the meta-analyses. When the included studies assessed outcomes using comparable methods, the effects of *Aronia melanocarpa* interventions were quantified using the mean difference (MD) with 95% confidence intervals (95% CI).

Statistical heterogeneity was assessed using Cochran's Q test and the I^2 index. The I^2 statistic, ranging from 0% and 100% values, was employed to quantify the extent of heterogeneity in effect sizes across studies. Values greater than 30%, 50%, and 75% were indicative of moderate, substantial, and high heterogeneity, respectively. Statistical significance was defined as a p-value of $p < 0.05$ for all analyses, with the exception of Cochran's Q test, for which a p-value of <0.10 was considered significant.

3 Results

3.1 Study Selection and Included Studies

Figure 1. presents the PRISMA flowchart that summarizes the literature search and study selection procedure. Initial database searches yielded a total of 118 records. Following the removal of 61 duplicate entries, 57 unique publications were identified. Subsequent screening of titles and abstracts led to the exclusion of 51 publications

due to irrelevant study designs, leaving six deemed potentially relevant. These six full-text publications were then critically evaluated for eligibility. One publication was excluded and it was not formally published, and another investigated a combination of pomegranate and *Aronia*, thus not meeting the single-intervention criterion. Consequently, a final total of 4 articles were included in this systematic review (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Lackner *et al.*, 2024; Le Sayec *et al.*, 2022).

3.2 Characteristics of Included Studies

The characteristics of the eligible studies are meticulously outlined in Table 1. Of the four articles analyzed, two investigated the effect of Aronia juice alone, (Chamberlin *et al.*, 2024; Lackner *et al.*, 2024), while the remaining two examined the impact of Aronia capsules (Istas *et al.*, 2019; Le Sayec *et al.*, 2022) on the gut microbiota. The reported doses of Aronia polyphenols were reported for periods ranging from 30 days to 12 weeks with a total polyphenol content of 12-1666 mg. A total of 200 participants were enrolled across the included studies, with individual sample sizes ranging from 14 to 85. The selected works were published between 2019 and 2024 and originated from three distinct countries: Austria (Lackner *et al.*, 2024), the USA (Chamberlin *et al.*, 2024), and the United Kingdom (Le Sayec *et al.*, 2022; Istas *et al.*, 2019) (Table 1).

All four RCTs assessed fecal microbiota-related outcomes, specifically focusing on relative abundance, alpha-diversity, and beta-diversity at both phylum and genus levels. However, none of the RCTs measured intestinal transit time, fecal form, dysbiosis indicators, and tight junctions. The mean difference values for changes in alpha-diversity data and bacterial genus and phylum evaluations were not consistently provided across the studies. Despite attempts to contact the corresponding authors, no additional data could be obtained. Consequently, a meta-analysis of gut microbiota composition at the phylum and genus levels could not be performed. A meta-analysis was, however, conducted for secondary outcomes, including vascular function parameters (augmentation index (AIx), pulse wave velocity (PWV), diastolic blood pressure (DBP); systolic blood pressure (SBP), blood flow velocity), biochemical parameters (fasting plasma glucose, high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol, triglycerides) and changes in phenolic metabolites following Aronia consumption.

3.3 Methodologies for Gut Microbiota Analysis and Reporting

The four RCTs included in the meta-analyses employed diverse techniques for analyzing and reporting gut microbiota data. Variations were observed in stool collection and DNA analysis methodologies across the studies. Two studies utilized OMNIgene GUT self-collection tubes (DNA Genotek) (Istas *et al.*, 2019; Le Sayec *et al.*, 2022), one study employed an unspecified type of self-collection tubes (Chamberlin *et al.*, 2024), and another utilized Meus S.R.L. stool collection tubes (Lackner *et al.*, 2024) for fecal sample collection. For DNA extraction, two studies employed the DNeasy PowerSoil Pro kits (QIAGEN, Germany) (Chamberlin *et al.*, 2024; Le Sayec *et al.*, 2022), while one study utilized the NucleoSpin Soil DNA Isolation Kit (Macherey-Nagel) (Istas *et al.*, 2019). In the remaining study, the Magna Pure LC DNA III Isolation Kit (Roche, Mannheim, Germany) was used for DNA extraction (Lackner *et al.*, 2024).

Regarding sequencing approaches, three of the studies targeted the 16S rRNA gene. Specifically, two studies focused on the V4 region, (Chamberlin *et al.*, 2024; Lackner *et al.*, 2024), and one study investigated the V3-V4 region, (Istas *et al.*, 2019). In contrast, one study applied shotgun metagenomics (Le Sayec *et al.*, 2022). For taxonomic evaluations, two studies utilized the Silva 136 and 132 databases, (Chamberlin *et al.*, 2024; Lackner *et al.*, 2024), one study employed the Ribosomal Database Project, (Istas *et al.*, 2019), and one study used the Integrated Gene Catalog (Le Sayec *et al.*, 2022).

3.4 Effect of *Aronia melanocarpa* Intervention on Gut Microbiota Ccomposition

The primary findings regarding the impact of *Aronia melanocarpa* on gut microbiota composition are summarized in Table 1.

Le Sayec *et al.* (2022) reported no significant change in alpha-diversity, as measured by Shannon-Wiener and Simpson indices, following 12 weeks of consumption of Aronia capsules containing 105.9 mg (poly)phenol. A significant increase in microbiome gene richness was observed in the Aronia group at the end of the intervention compared to baseline (mean value of 12.33 ± 112.1 for Aronia group, vs 30.05 ± 108.9 (p = 0.02). Furthermore, a significant increase was noted in the abundance of several species (n = 12) within the Aronia-consuming group, including *Intestinimonas butyriciproducens* (p = 0.014, effect size = 0.30), *Lawsonibacter asaccharolyticus* (p = 0.04, effect size = 0.26), *Butyricimonas faecihominis* (p = 0.05, effect size = 0.23), *Bacteroides xylanisolvens* (p = 0.05, effect size = 0.23), and *Senegalimassilia anaerobia* (p = 0.03, effect size = -0.26). Additionally, the abundance of *Haemophilus parainfluenzae* was significantly elevated (p = 0.03, effect size = -0.20).

Chamberlin *et al.* (2024) investigated the daily consumption of 100 mL of Aronia juice for 30 days (total

(poly)phenol unspecified, 3.20 g Cyanidin 3-glucoside) and observed no difference in microbial equilibrium between the Aronia and placebo groups, as quantified by Pielou's equation. While a decrease in the abundance of *Holdemania* and *Barnesiella* and an increase in three unidentified genera within Oxalobacteraceae, Prevotellaceae, and Pasturellaceae were noticed with Aronia consumption, these differences did not remain significant after multiple testing corrections.

In the study by Istas *et al.* (2019), participants consumed Aronia capsules (116 mg) and aronia fruit capsules (23 mg (poly)phenol) for 12 weeks. Microbial diversity remained very high and non-significant across all treatment groups following Aronia intake. A significant increase in *Anaerostipes* was observed in the Aronia capsule intervention group (+10.6%, p = 0.01), while a significant increase in *Bacteroides* was observed in the Aronia fruit capsule group (+193%, p = 0.01). In contrast, *Clostridium* XIVb was significantly elevated (+2.5%, p = 0.01) following placebo treatment.

Lackner *et al.* (2024) administered 200 mL of Aronia juice (1666 mg (poly)phenol) to healthy individuals for 6 weeks. Alpha-diversity, evaluated using the Shannon index increased significantly in the Aronia group (p = 0.046) but remained constant in the placebo group. Ribosomal sequence variants of the genus *Anaerostipes* increased in the Aronia-consuming group at 6 weeks and subsequently decreased after a 6–12-week washout period (p = 0.03 and p = 0.47, respectively). The genus *Bacteroides* was not significantly affected by Aronia consumption during the 0–6-week intervention period but displayed a significant increase over the 0–12-week and 6–12-week periods (p = 0.042 and p = 0.028, respectively).

3.5 Effect on β-diversity

Regarding β-diversity, Le Sayec *et al.* (2022) reported no significant alterations when assessed by the Bray-Curtis dissimilarity index. Similarly, Chamberlin *et al.* (2024) observed no discernible changes in either the microbial features selected by hierarchical trait engineering or the overall composition of the microbial community at any taxonomic level following the intervention. The investigation by Istas *et al.* (2019) also indicated that microbial diversity remained consistently high and non-significant across all treatment groups after Aronia consumption. Likewise, Lackner *et al.* (2024) did not identify significant changes in beta diversity.

3.6 Evaluation of Phenolic Metabolites

Three studies (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Le Sayec *et al.*, 2022) quantified the effect of Aronia consumption on plasma levels of total phenolic metabolites. The meta-analysis revealed that Aronia consumption significantly increased plasma stilbenes levels, while no significant changes were observed for flavanols and total polyphenols (Figure 2). Specifically, the analysis revealed that Aronia intervention led to a significant increase in the level of stilbenes compared to the control group (MD): 0.11,

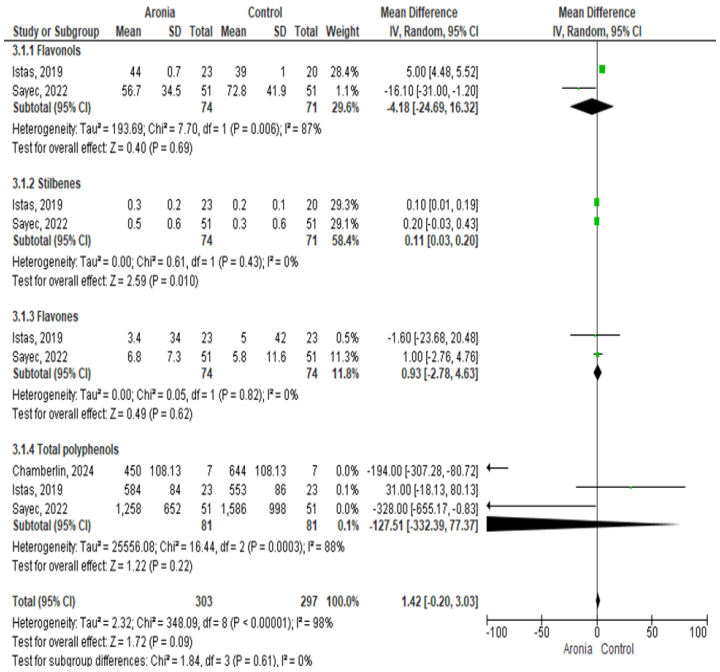

Figure 2. Forest plot of the activity phenolic metabolites in plasma in participants

95% CI: 0.03 to 0.20, Z = 2.59, p = 0.010). Regarding heterogeneity in the effect of Aronia consumption on total phenolic metabolites in plasma, no significant heterogeneity was observed between the groups, with the exception of flavanols (I^2 = 87%, p = 0.006).

3.7 Impact of *Aronia melanocarpa* Intervention on Markers of Health Status

Three studies (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Le Sayec *et al.*, 2022) measured and reported the effect of Aronia consumption on lipid profile and blood glucose (Figure 3). The assessed parameters included high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol, triglycerides, and fasting plasma glucose. The meta-analysis indicated that while Aronia intervention resulted in a decrease in fasting plasma glucose (MD: 0.07, 95% CI: -0.07 to 0.20, p = 0.34), cholesterol (MD: 0.06, 95% CI: -0.22 to 0.35, p = 0.06), triglycerides (MD: 0.02, 95% CI: -0.10 to 0.13, p = 0.80) and HDL (MD: 0.12, 95% CI: 0.00 to 0.23, p = 0.05) and decreased LDL (MD: -0.04, 95% CI: -0.30 to 0.22, p = 0.76), but there was no significant difference (MD: 0.06, 95% CI: - 0.01 to 0.13, p = 0.08). Aronia consumption had no significant effect on biochemical data (Figure 3). Among the biochemical data, moderate heterogeneity was observed for triglycerides (I^2 = 35%, p = 0.02) and HDL (I^2 = 31%, p = 0.24), while other parameters displayed no significant heterogeneity.

3.8 Effect of *Aronia melanocarpa* Intervention on Vascular Function

Three studies (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Le Sayec *et al.*, 2022) assessed and reported the effect of Aronia consumption on vascular function. Overall, the meta-analyses revealed no significant effect of Aronia consumption on the evaluated vascular parameters. Specifically, Aronia intervention demonstrated no significant effect on blood flow velocity (MD: 4.01, 95% CI: -3.85 to 11.87, p = 0.32), pulse wave velocity (PWV) (MD: 0.06, 95% CI: -0.29 to 0.42, p = 0.73;), heart rate (MD: 2.56, 95% CI: -0.53 to 5.64, p = 0.10), augmentation index (AIx) (MD: -2.69, 95% CI: -7.48 to 2.09, p = 0.27), systolic blood pressure (SBP) (MD: -0.36, 95% CI: -3.52 to 2.79, p = 0.82), or diastolic blood pressure (DBP) (MD: -0.39, 95% CI: -2.56 to 1.78, p = 0.73). Furthermore, no significant heterogeneity was detected across studies for vascular function parameters (I^2 = 0%, p = 0.66).

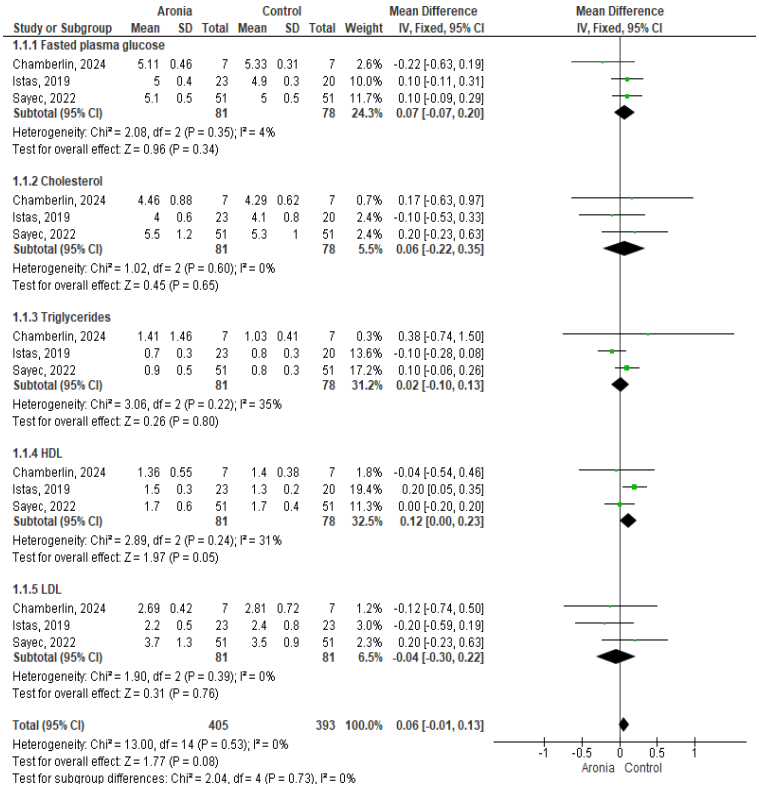

Figure 3. Forest plot of lipid profile parameters and fasting plasma glucose in participant

3.9 Effect of *Aronia melanocarpa* Intervention on Changes in Functional Potential

Regarding metabolic potential, Le Sayec *et al.* (2022) observed an estimated 2% variation in metabolic potential after 12 weeks, with 17 functional modules exhibiting notable group variations. Notably, the Aronia group demonstrated higher levels of the Gut-Brain Module, which is associated with propionate production, and the gut microbial module involved in gamma-aminobutyric acid biosynthesis (p = 0.08), compared to the control group. Following the intervention, Chamberlin *et al.* (2024) identified significantly higher fasting levels of both tyrosine and asparagine in the group that consumed Aronia. Additionally, an analysis of fecal diversity indicated an increase in the principal bile acid metabolite, chenodeoxycholic acid (CDCA), in individuals consuming Aronia. A comparable rise in CDCA levels after Aronia use was also reported in the investigation by Lackner *et al.* (2024).

3.10 Risk of Bias

The methodological quality of the included RCTs was assessed using the Cochrane risk of bias assessment tool. All four studies reported adequate procedures for sequence generation, leading to a low risk of bias in this domain. Blinding of both participants and personnel was employed across all studies included in the meta-analysis. Losses to follow-up between the intervention and control groups were either balanced or deemed insufficient to impact the study outcomes. However, an unclear risk of bias was identified concerning trial enrollment and reporting bias, as not all studies reported negative outcomes. Le Sayec *et al.* (2022) and Chamberlin *et al.* (2024) did not provide sufficient information regarding these potentially biased areas. A comprehensive graphical representation of the quality evaluation findings for the included research is presented in Figure 4.

Figure 4. Risk of bias summary and graph

4 Discussion

Aronia melanocarpa fruit, distinguished by its high polyphenol content, is increasingly recognized for its efficacy in preventing chronic diseases such as diabetes, cardiovascular diseases, as well as for its immune-protective properties. Furthermore, its capacity to enhance beneficial bacteria and augment intestinal microbial diversity, and becoming an increasingly recognized plant as an intestinal microbiome regulator (Jurikova *et al.*, 2017; Mompeo *et al.*, 2020). The pivotal role of the intestinal microbiome in polyphenol metabolism has been well-established (Espín *et al.*, 2017).

The primary objective of this study was to investigate the hypothesis that Aronia consumption may foster gut microbiota health through a prebiotic effect. A comprehensive literature review identified four RCTs examining the impact of Aronia consumption on microbiota, phenolic metabolites, and biochemical markers. Generally, two of these studies reported significant alterations in certain bacterial phyla and some genera within the microbiota following Aronia consumption (Istas *et al.*, 2019; Le Sayec *et al.*, 2022). Both of these interventions featured a 12-week duration and involved *Aronia melanocarpa* species with high polyphenol content. Istas *et al.* (2019) specifically demonstrated that consumption of *Aronia melanocarpa* fruit and extract may modulate the gut microbiome. Similarly, Lackner *et al.* (2024) observed a significant increase in *Anaerostipes* abundance following consumption of *Aronia melanocarpa* juice. The genus *Anaerostipes* plays crucial role in the intestinal ecosystem attributed to its capacity to produce butyrate from lactate (Muñoz-Tamayo *et al.*, 2011). Thus, the enrichment of butyrate-producing bacteria supports the hypothesis that Aronia consumption may exert a prebiotic effect (Creedon *et al.*, 2020). Butyrate, a short-chain fatty acid, has been associated with beneficial effects in a range of conditions,

including genetic metabolic disorders, hypercholesterolemia, insulin resistance, ischemic stroke, and colon cancer (Canani *et al.*, 2011). Furthermore, Istas *et al.* (2019) demonstrated that consumption of *Aronia melanocarpa* fruit capsules would increase the abundance of *Bacteroides*. While increases in certain genera such as *Bacteroides* have been associated with adverse health outcomes in some microbiome assessments (Nash *et al.*, 2018), a few studies have correlated *Bacteroides* with improved health. For instance, *Bacteroides* abundance was found to increase in obese individuals who achieved weight loss (Turnbaugh *et al.*, 2006), and polysaccharide A produced by *Bacteroides* has been shown to prevent inflammatory bowel disease in animal models (Mazmanian *et al.*, 2008). A review published in 2018, based on human clinical trials, similarly examined the effects of grape and red wine polyphenols on gut microbiota composition. That study reported increases in the populations of *Enterococcus, Prevotella, Bacteroides, Bifidobacterium, Bacteroides uniformis, Eggerthella lenta*, and the *Blautia coccoides – Eubacterium rectale* group following polyphenol intake. Conversely, a decrease was observed in *Actinobacteria, Clostridium* spp., and the *Clostridium histolyticum* group. Additionally, in cases of non-alcoholic consumption, an increase in *Fusobacteria* and *Firmicutes* populations and a decrease in *Actinobacteria* were reported (Costa *et al.*, 2019; Cueva *et al.*, 2017; Gil-Sánchez *et al.*, 2018). Consistent with these findings, Le Sayec *et al.* (2022) reported that Aronia capsules increased the levels of butyrate-producing species, such as *I. butyriciproducens* and *B. faecihominis*. A study by Baenas *et al.* (2020) analyzed polyphenols from raspberries using an *in vitro* fermentation model and examined metabolites such as short-chain fatty acids (SCFAs). The results indicated that the identified polyphenols, primarily hydrolyzable polyphenols found in the insoluble fraction of fiber fraction, were the main compounds responsible for the prebiotic effect of raspberries (Baenas *et al.*, 2020). This study concluded that raspberries or raspberry extract could serve as a prebiotic substrate in foods, functional foods, and dietary supplements through their antimicrobial and antioxidant effects (Rodríguez-Costa *et al.*, 2018). Another review study examined the effects of fruit polyphenols on the intestinal microbiota and found that high amounts of polyphenols can reach the colon, where they can contribute to the formation of various metabolites. While fruit polyphenols increase the growth of beneficial bacteria such as *Bifidobacterium*, *Lactobacillus*, *Akkermansia*, *Bacteroides*, and *Eubacterium*, they can simultaneously reduce the number of harmful bacteria such as *Pseudomonas*, *Salmonella*, *Staphylococcus*, and *Bacillus*. Although the precise mechanisms in *in vitro* studies are not yet fully elucidated, a high production of short-chain fatty acids (SCFA) has been observed across several studies, suggesting a prebiotic-like effect of polyphenols (Pozuelo *et al.*, 2012). A statistically non-significant increase in the next-generation probiotic species *F. prausnitzii* was also noted. *F. prausnitzii*, one of the most prevalent taxa in the gut, may be essential for preserving gut homeostasis (Le Sayec *et al.*, 2022; Lopez-Siles *et al.*, 2017). Consistent with the above findings, Chamberlin *et al.* (2024) observed that Aronia juice consumption was associated with a decrease in the abundance of *Holdemania* and *Barnesiella* and an increase in the abundance of three undescribed genera within *Oxalobacteraceae*, *Prevotellaceae*, and *Pasturellaceae*; however, these associations were not sustained after multiple testing.

In the context of gut microbiota and health, high levels of bacterial diversity are typically associated to favorable health outcomes, whereas low bacterial diversity has been identified as a contributing factor in various disease states. Dietary factors that enhance α-diversity, which refers to the number of unique taxa present in each sample as an indicator of microbial diversity within that sample, are particularly valuable, as they may reduce the risk of disease and promote health in otherwise healthy individuals (Creedon *et al.*, 2020; Finotello *et al.*, 2018). All three reviewed studies (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Le Sayec *et al.*, 2022) reported on the effect of Aronia consumption on α-diversity. Lackner *et al.* (2024), however, uniquely identified a significant increase in α-diversity in the Aronia-consuming group. β-diversity reflects the variation in taxa composition between different samples. In dietary studies, it typically represents the differences in bacterial communities before and after an intervention (Creedon *et al.*, 2020). Due to inconsistencies in the reporting of β-diversity measures across the studies, a meta-analysis could not be performed. Le Sayec and Chamberlin reported no significant differences in β-diversity (Chamberlin *et al.*, 2024; Le Sayec *et al.*, 2022).

The primary polyphenols in *Aronia melanocarpa* are anthocyanins, proanthocyanidins, flavonoids, and phenolic acids (Sweeney *et al.*, 2022). While Aronia fruit exhibits a higher antioxidant potential than various other dietary sources, the included studies did not fully account for the complexities of polyphenol metabolism and bioavailability. Numerous elements affect bioavailability, such as the chemicals' physicochemical stability, complex formation capacity, interactions with food, gastrointestinal absorption, and intestinal and hepatic metabolism (King & Bolling, 2020). The intestinal microbiota plays a crucial role in the conversion of flavonoids and other dietary phenolic compounds from the parent molecule to metabolites with greater bioactivity (Sweeney *et al.*, 2022). The metabolism of several polyphenols, including flavanones, lignans, prenylflavonoids, proanthocyanidins, anthocyanins, and stilbenes, shows high interindividual variability (Quesada-Vázquez *et al.*, 2024). For instance, large polyphenols such as

ellagitannins cannot be absorbed by the human intestine unless they are converted into bioavailable forms by the gut (Sweeney *et al.*, 2022). In our study, meta-analyses of studies evaluating plasma phenolic metabolite levels found that Aronia consumption caused a significant difference in stilbenes levels among nonflavonoid polyphenols. According to the results of the analyses, it was found that stilbenes levels increased in the group consuming *Aronia melanocarpa* compared to the control, and there was a significant effect between the groups (Figure 2). Stilbenes may contribute to reducing obesity by regulating various pathways, with some stilbenes even demonstrating superior anti-obesity activity compared to resveratrol (Benbouguerra *et al.*, 2021). The significant increase in stilbenes levels following *Aronia melanocarpa* consumption of is, therefore, a noteworthy finding. In addition, Istac *et al.* (2019) reported that the total plasma polyphenol concentration after consumption of whole Aronia fruit and Aronia extract was 30 ± 156 µM and 14 ± 106 µM, respectively. Le Sayec *et al.* (2022) did not detect any significant change in plasma metabolites after 12 weeks of Aronia capsule intervention. Nevertheless, a notable rise in plasma phenolic metabolites was observed two hours after taking *Aronia melanocarpa* capsules, both on day one (12 cinnamic acid, 5 benzoic acid, and 1 flavonol derivative), and after 12 weeks (6 cinnamic acids, 5 benzoic acid, and 1 phenylpropanoic acid derivative).

Contemporary national nutrition and health programs strongly advocate for the increased consumption of fruits and vegetables. Indeed, their rich abundance in diverse polyphenols and other phytonutrients provides strong antioxidant capacities that can potentially prevent or reduce the occurrence of chronic diseases (Quesada-Vázquez *et al.*, 2024). When evaluating the effect of studies on health parameters, three interventions (Chamberlin *et al.*, 2024; Istas *et al.*, 2019; Le Sayec *et al.*, 2022) assessed the effect of Aronia consumption on vascular function and biochemical parameters. Meta-analyses revealed no significant effect of Aronia consumption on vascular function and biochemical parameters (Figure 4). In contrast, the study by Lackner *et al.* (2024), which was excluded from the meta-analysis, indicated that an Aronia juice intervention altered human lipoprotein metabolism in several ways, with these alterations persisting for multiple weeks post-intervention. Although not detected in our study, previous research has associated the consumption of red fruits with a decrease in blood pressure (Borghi *et al.*, 2020; Cicero *et al.*, 2019; Cicero *et al.*, 2021). An analysis of regular flavonoid intake in the Nurses' Health Study and Health Professionals Follow-up Study cohorts linked the highest anthocyanin intake, primarily from fruits, to an 8% decrease in the incidence of hypertension (Cassidy *et al.*, 2011). Given that these studies evaluated longer-term red fruit and flavonoid intakes, 4–12 weeks of consumption in our included studies may not have been sufficient to demonstrate significant results in blood pressure.

In addition, Lackner *et al.* (2024) examined the tolerance status in Aronia consumption. Various food molecules, such as tannins, proteins, and polysaccharides, present in Aronia, can interact with salivary proteins, leading to sensations of bitterness and astringency. The bitter mouthfeel and reduced saliva flow rate were associated with complaints of gas, cramps, and bloating. Despite these reported symptoms, O-glycan levels were found to be elevated even in the group experiencing these symptoms. O-glycans are key components of intestinal mucus, forming the protective mucus layer of the intestinal epithelium. They are essential for preserving intestinal health by influencing barrier integrity, inhibiting pathogen adhesion, controlling immunological responses, and shaping the mucus environment.

Strength and Limitations

A significant strength of this study lies in its adherence to the PRISMA guidelines (Page *et al.*, 2021) and the Cochrane Handbook for Systematic Reviews of Interventions (Higgins *et al.*, 2020) to establish a robust search strategy. The prospective registration and publication of the study protocol (PROSPERO registration No. CRD42024593226) further minimized reviewer bias. To the best of our knowledge, this investigation represents the first systematic evaluation detailing the bioavailability of secondary metabolites contained in *Aronia melanocarpa* and their effect on the gut microbiota. In addition, the exclusive inclusion of randomized controlled human studies enhances the reliability of the review and permits an assessment of efficacy within the complex human gut flora.

Despite these strengths, certain limitations in outcome reporting were identified. The primary limitation of this review is the restricted number of high-quality RCTs focused exclusively on *Aronia melanocarpa*. Additionally, inconsistencies in reporting microbial diversity metrics and the lack of standardization in DNA extraction and sequencing methods contribute to the heterogeneity observed across studies. In addition, the non-uniformity of secondary metabolite content in specific Aronia supplements limited the sensitivity of outcome assessments and the precise determination of optimal dosages. Variations in trial duration and measurement techniques across the included studies also posed challenges. Most of the existing studies were shorter than three months, indicating a need for longer-term clinical studies to thoroughly evaluate sustained effects.

5 Conclusion

This systematic review and meta-analysis highlight the positive effects of *Aronia melanocarpa* on the gut microbiota.

Human clinical trials, especially those with a 12-week intervention period and utilizing extracts with high polyphenol content, suggest that Aronia may positively modulate the gut microbiota and exert a prebiotic effect. However, no statistically significant positive effects on broader health parameters were reported in the meta-analysis. This outcome may be attributable to variations in dosage, intervention period, and individual differences.

To obtain robust results regarding the effect on gut microbiota and gut health, and to achieve clarity on optimal dosage and intervention period, future RCTs with sufficient statistical power are necessary. These trials should be designed to detect changes in primary outcomes related to gut microbiota and to integrate clinical functional outcomes. Moreover, various intrinsic and extrinsic factors such as diet composition, age, drug use, and host genetics may affect microbiota. If these factors are not adequately controlled, generalizing the effects of *Aronia melanocarpa* on microbiota may not be appropriate.

Acknowledgment: We acknowledge the authors of every study that was a part of this investigation.

Source of funding: None declared.

Previous submissions: The manuscript has not been presented in any scientific forum or meeting.

Authors' Contribution: Berrak Basturk: Data curation, Formal Analysis, Investigation, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Zeynep Koc Ozerson**: Data curation, Formal Analysis, Editing. **Aysu Yildiz Karaahmet**: Data curation, Formal Analysis, Software, Investigation, Resources, Validation, Writing – review & editing. **Kardelen Busra Ege Gunduz**: Formal Analysis, Software, Validation, Investigation, review & editing. **Sumeyye Bora**: Formal Analysis, Software, Validation, review & editing.

Conflicts of Interest: No conflicts of interest are disclosed by the writers.

Preprint deposit: Authors did not share this manuscript as a preprint deposit.

REFERENCES

Baenas, N., Nuñez-Gómez, V., Navarro-González, I., Sánchez-Martínez, L., García-Alonso, J., Periago, M. J., & González-Barrio, R. (2020). Raspberry dietary fibre: Chemical properties, functional evaluation and prebiotic in vitro effect. *Lebensmittel-Wissenschaft Und Technologie [Food Science and Technology]*, *134*(110140), 110140. https://doi.org/10.1016/j.lwt.2020.110140 [Crossref] [Google Scholar] [Publisher]

Benbouguerra, N., Hornedo-Ortega, R., Garcia, F., El Khawand, T., Saucier, C., & Richard, T. (2021). Stilbenes in grape berries and wine and their potential role as anti-obesity agents: A review. *Trends in Food Science & Technology*, *112*, 362–381. https://doi.org/10.1016/j.tifs.2021.03.060 [Crossref] [Google Scholar] [Publisher]

Borghi, C., Tsioufis, K., Agabiti-Rosei, E., Burnier, M., Cicero, A. F. G., Clement, D., Coca, A., Desideri, G., Grassi, G., Lovic, D., Lurbe, E., Kahan, T., Kreutz, R., Jelakovic, B., Polonia, J., Redon, J., Van De Borne, P., & Mancia, G. (2020). Nutraceuticals and blood pressure control: a European Society of Hypertension position document. *Journal of Hypertension*, *38*(5), 799–812. https://doi.org/10.1097/HJH.0000000000002353 [Crossref] [PubMed] [Google Scholar] [Publisher]

Canani, Roberto Berni, Costanzo, M. D., Leone, L., Pedata, M., Meli, R., & Calignano, A. (2011). Potential beneficial effects of butyrate in intestinal and extraintestinal diseases. *World Journal of Gastroenterology: WJG*, *17*(12), 1519–1528. https://doi.org/10.3748/wjg.v17.i12.1519 [Crossref] [PubMed] [Google Scholar] [Publisher]

Cassidy, A., O'Reilly, É. J., Kay, C., Sampson, L., Franz, M., Forman, J. P., Curhan, G., & Rimm, E. B. (2011). Habitual intake of flavonoid subclasses and incident hypertension in adults. *The American Journal of Clinical Nutrition*, *93*(2), 338–347. https://doi.org/10.3945/ajcn.110.006783 [Crossref] [PubMed] [Google Scholar] [Publisher]

Chamberlin, M. L., Peach, J. T., Wilson, S. M. G., Miller, Z. T., Bothner, B., Walk, S. T., Yeoman, C. J., & Miles, M. P. (2024). Polyphenol-rich *Aronia melanocarpa* fruit beneficially impact cholesterol, glucose, and serum and gut metabolites: A randomized clinical trial. *Foods (Basel, Switzerland)*, *13*(17), 2768. https://doi.org/10.3390/foods13172768 [Crossref] [PubMed] [Google Scholar] [Publisher]

Cicero, A. F. G., Grassi, D., Tocci, G., Galletti, F., Borghi, C., & Ferri, C. (2019). Nutrients and nutraceuticals for the management of high normal blood pressure: An evidence-based consensus document. *High Blood Pressure & Cardiovascular Prevention: The Official Journal of the Italian Society of Hypertension*, *26*(1), 9–25. https://doi.org/10.1007/s40292-018-0296-6 [Crossref] [PubMed] [Google Scholar] [Publisher]

Cicero, A. F. G., Veronesi, M., & Fogacci, F. (2021). Dietary intervention to improve blood pressure control: Beyond salt restriction. *High Blood Pressure & Cardiovascular Prevention: The Official Journal of the Italian Society of Hypertension*, *28*(6), 547–553.

https://doi.org/10.1007/s40292-021-00474-6 [Crossref] [PubMed] [Google Scholar] [Publisher]

Costa, J. R., Amorim, M., Vilas-Boas, A., Tonon, R. V., Cabral, L. M. C., Pastrana, L., & Pintado, M. (2019). Impact of in vitro gastrointestinal digestion on the chemical composition, bioactive properties, and cytotoxicity of Vitis vinifera L. cv. Syrah grape pomace extract. *Food & Function*, *10*(4), 1856–1869. https://doi.org/10.1039/c8fo02534g [Crossref] [PubMed] [Google Scholar] [Publisher]

Creedon, A. C., Hung, E. S., Berry, S. E., & Whelan, K. (2020). Nuts and their effect on gut Microbiota, gut function and symptoms in adults: A systematic review and meta-analysis of randomised controlled trials. *Nutrients*, *12*(8), 2347. https://doi.org/10.3390/nu12082347 [Crossref] [PubMed] [Google Scholar] [Publisher]

Cueva, C., Gil-Sánchez, I., Ayuda-Durán, B., González-Manzano, S., González-Paramás, A. M., Santos-Buelga, C., Bartolomé, B., & Moreno-Arribas, M. V. (2017). An integrated view of the effects of wine polyphenols and their relevant metabolites on gut and host health. Molecules (Basel, Switzerland), 22(1), 99. https://doi.org/10.3390/molecules22010099 [Crossref] [PubMed] [Google Scholar] [Publisher]

Espín, J. C., González-Sarrías, A., & Tomás-Barberán, F. A. (2017). The gut microbiota: A key factor in the therapeutic effects of (poly)phenols. *Biochemical Pharmacology*, *139*, 82–93. https://doi.org/10.1016/j.bcp.2017.04.033 [Crossref] [PubMed] [Google Scholar] [Publisher]

Finotello, F., Mastrorilli, E., & Di Camillo, B. (2018). Measuring the diversity of the human microbiota with targeted next-generation sequencing. *Briefings in Bioinformatics*, *19*(4), 679–692. https://doi.org/10.1093/bib/bbw119 [Crossref] [PubMed] [Google Scholar] [Publisher]

Gil-Sánchez, I., Cueva, C., Sanz-Buenhombre, M., Guadarrama, A., Moreno-Arribas, M. V., & Bartolomé, B. (2018). Dynamic gastrointestinal digestion of grape pomace extracts: Bioaccessible phenolic metabolites and impact on human gut microbiota. *Journal of Food Composition and Analysis: An Official Publication of the United Nations University, International Network of Food Data Systems*, *68*, 41–52. https://doi.org/10.1016/j.jfca.2017.05.005 [Crossref] [Google Scholar] [Publisher]

Gurčík, Ľ., Bajusová, Z., Ladvenicová, J., Palkovič, J., & Novotná, K. (2023). Cultivation and processing of modern superfood—*Aronia melanocarpa* (black chokeberry) in Slovak Republic. *Agriculture*, *13*(3), 604. https://doi.org/10.3390/agriculture13030604 [Crossref] [Google Scholar] [Publisher]

Higgins, J., (2011). *Cochrane handbook for systematic reviews of interventions*. Cochrane.org. Retrieved 10 October 2024) [Google Scholar] [Publisher]

Istas, G., Wood, E., Le Sayec, M., Rawlings, C., Yoon, J., Dandavate, V., Cera, D., Rampelli, S., Costabile, A., Fromentin, E., & Rodriguez-Mateos, A. (2019). Effects of aronia berry (poly)phenols on vascular function and gut microbiota: a double-blind randomized controlled trial in adult men. *The American Journal of Clinical Nutrition*, *110*(2), 316–329. https://doi.org/10.1093/ajcn/nqz075 [Crossref] [PubMed] [Google Scholar] [Publisher]

Jurendić, T., & Ščetar, M. (2021). *Aronia melanocarpa* products and by-products for health and nutrition: A review. *Antioxidants (Basel, Switzerland)*, *10*(7), 1052. https://doi.org/10.3390/antiox10071052 [Crossref] [PubMed] [Google Scholar] [Publisher]

Jurikova, T., Mlcek, J., Skrovankova, S., Sumczynski, D., Sochor, J., Hlavacova, I., Snopek, L., & Orsavova, J. (2017). Fruits of black chokeberry *Aronia melanocarpa* in the prevention of chronic diseases. *Molecules (Basel, Switzerland)*, *22*(6). https://doi.org/10.3390/molecules22060944 [Crossref] [PubMed] [Google Scholar] [Publisher]

King, E. S., & Bolling, B. W. (2020). Composition, polyphenol bioavailability, and health benefits of aronia berry: a review. *Journal of Food Bioactives: An Official Scientific Publication of the International Society of Nutraceuticals and Functional Foods (ISNFF)*, *11*, 13–30. https://doi.org/10.31665/jfb.2020.11235 [Crossref] [Google Scholar] [Publisher]

Lackner, S., Mahnert, A., Moissl-Eichinger, C., Madl, T., Habisch, H., Meier-Allard, N., Kumpitsch, C., Lahousen, T., Kohlhammer-Dohr, A., Mörkl, S., Strobl, H., & Holasek, S. (2024). Interindividual differences in aronia juice tolerability linked to gut microbiome and metabolome changes-secondary analysis of a randomized placebo-controlled parallel intervention trial. *Microbiome*, *12*(1), 49. https://doi.org/10.1186/s40168-024-01774-4 [Crossref] [PubMed] [Google Scholar] [Publisher]

Le Sayec, M., Xu, Y., Laiola, M., Gallego, F. A., Katsikioti, D., Durbidge, C., Kivisild, U., Armes, S., Lecomte, M., Fança-Berthon, P., Fromentin, E., Plaza Oñate, F., Cruickshank, J. K., & Rodriguez-Mateos, A. (2022). The effects of Aronia berry (poly)phenol supplementation on arterial function and the gut

microbiome in middle aged men and women: Results from a randomized controlled trial. *Clinical Nutrition (Edinburgh, Scotland)*, *41*(11), 2549–2561. https://doi.org/10.1016/j.clnu.2022.08.024 [Crossref] [PubMed] [Google Scholar] [Publisher]

Lopez-Siles, M., Duncan, S. H., Garcia-Gil, L. J., & Martinez-Medina, M. (2017). Faecalibacterium prausnitzii: from microbiology to diagnostics and prognostics. *The ISME Journal*, *11*(4), 841–852. https://doi.org/10.1038/ismej.2016.176 [Crossref] [PubMed] [Google Scholar] [Publisher]

Lotti, S., Dinu, M., Colombini, B., Amedei, A., & Sofi, F. (2023). Circadian rhythms, gut microbiota, and diet: Possible implications for health. *Nutrition, Metabolism, and Cardiovascular Diseases: NMCD*, *33*(8), 1490–1500. https://doi.org/10.1016/j.numecd.2023.05.009 [Crossref] [PubMed] [Google Scholar] [Publisher]

Mazmanian, S. K., Round, J. L., & Kasper, D. L. (2008). A microbial symbiosis factor prevents intestinal inflammatory disease. *Nature*, *453*(7195), 620–625. https://doi.org/10.1038/nature07008 [Crossref] [PubMed] [Google Scholar] [Publisher]

Mompeo, O., Spector, T. D., Matey Hernandez, M., Le Roy, C., Istas, G., Le Sayec, M., Mangino, M., Jennings, A., Rodriguez-Mateos, A., Valdes, A. M., & Menni, C. (2020). Consumption of Stilbenes and flavonoids is linked to reduced risk of obesity independently of fiber intake. *Nutrients*, *12*(6), 1871. https://doi.org/10.3390/nu12061871 [Crossref] [PubMed] [Google Scholar] [Publisher]

Muñoz-Tamayo, R., Laroche, B., Walter, E., Doré, J., Duncan, S. H., Flint, H. J., & Leclerc, M. (2011). Kinetic modelling of lactate utilization and butyrate production by key human colonic bacterial species: Modelling butyrate production by colonic bacterial species. *FEMS Microbiology Ecology*, *76*(3), 615–624. https://doi.org/10.1111/j.1574-6941.2011.01085.x [Crossref] [PubMed] [Google Scholar] [Publisher]

Nash, V., Ranadheera, C. S., Georgousopoulou, E. N., Mellor, D. D., Panagiotakos, D. B., McKune, A. J., Kellett, J., & Naumovski, N. (2018). The effects of grape and red wine polyphenols on gut microbiota - A systematic review. *Food Research International (Ottawa, Ont.)*, *113*, 277–287. https://doi.org/10.1016/j.foodres.2018.07.019 [Crossref] [PubMed] [Google Scholar] [Publisher]

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, n71. https://doi.org/10.1136/bmj.n71 [Crossref] [PubMed] [Google Scholar] [Publisher]

Pozuelo, M. J., Agis-Torres, A., Hervert-Hernández, D., Elvira López-Oliva, M., Muñoz-Martínez, E., Rotger, R., & Goñi, I. (2012). Grape antioxidant dietary fiber stimulates Lactobacillus growth in rat cecum. *Journal of Food Science*, *77*(2), H59-62. https://doi.org/10.1111/j.1750-3841.2011.02520.x [Crossref] [PubMed] [Google Scholar] [Publisher]

Quesada-Vázquez, S., Eseberri, I., Les, F., Pérez-Matute, P., Herranz-López, M., Atgié, C., Lopez-Yus, M., Aranaz, P., Oteo, J. A., Escoté, X., Lorente-Cebrian, S., Roche, E., Courtois, A., López, V., Portillo, M. P., Milagro, F. I., & Carpéné, C. (2024). Polyphenols and metabolism: from present knowledge to future challenges. *Journal of Physiology and Biochemistry*, *80*(3), 603–625. https://doi.org/10.1007/s13105-024-01046-7 [Crossref] [PubMed] [Google Scholar] [Publisher]

Ren, Y., Frank, T., Meyer, G., Lei, J., Grebenc, J. R., Slaughter, R., Gao, Y. G., & Kinghorn, A. D. (2022). Potential benefits of black chokeberry (*Aronia melanocarpa*) fruits and their constituents in improving human health. *Molecules (Basel, Switzerland)*, *27*(22), 7823. https://doi.org/10.3390/molecules27227823 [Crossref] [PubMed] [Google Scholar] [Publisher]

Rodríguez-Costa, S., Cardelle-Cobas, A., Roca-Saavedra, P., Porto-Arias, J. J., Miranda, J. M., & Cepeda, A. (2018). In vitro evaluation of the prebiotic effect of red and white grape polyphenolic extracts. *Journal of Physiology and Biochemistry*, *74*(1), 101–110. https://doi.org/10.1007/s13105-017-0573-1 [Crossref] [PubMed] [Google Scholar] [Publisher]

Sweeney, M., Burns, G., Sturgeon, N., Mears, K., Stote, K., & Blanton, C. (2022). The effects of berry polyphenols on the gut Microbiota and blood pressure: A systematic review of randomized clinical trials in humans. *Nutrients*, *14*(11), 2263. https://doi.org/10.3390/nu14112263 [Crossref] [PubMed] [Google Scholar] [Publisher]

Taheri, R., Connolly, B. A., Brand, M. H., & Bolling, B. W. (2013). Underutilized chokeberry (*Aronia melanocarpa*, *Aronia arbutifolia*, *Aronia prunifolia*) accessions are rich sources of anthocyanins, flavonoids, hydroxycinnamic acids, and proanthocyanidins. *Journal of Agricultural and Food Chemistry*, *61*(36), 8581–8588.

https://doi.org/10.1021/jf402449q [Crossref] [PubMed] [Google Scholar] [Publisher]

Turnbaugh, P. J., Ley, R. E., Mahowald, M. A., Magrini, V., Mardis, E. R., & Gordon, J. I. (2006). An obesity-associated gut microbiome with increased capacity for energy harvest. *Nature*, *444*(7122), 1027–1031. https://doi.org/10.1038/nature05414 [Crossref] [PubMed] [Google Scholar] [Publisher]

Wilson, S. M. G., Peach, J. T., Fausset, H., Miller, Z. T., Walk, S. T., Yeoman, C. J., Bothner, B., & Miles, M. P. (2023). Metabolic impact of polyphenol-rich aronia fruit juice mediated by inflammation status of gut microbiome donors in humanized mouse model. *Frontiers in Nutrition*, *10*, 1244692. https://doi.org/10.3389/fnut.2023.1244692 [Crossref] [PubMed] [Google Scholar] [Publisher]