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1 **Anthocyanins and metabolites resolve TNF- α -mediated production of E-selectin and adhesion**
2 **of monocytes to endothelial cells**

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12 **RUNNING TITLE:** Anthocyanins and metabolites reduce inflammation

13

14 **ABBREVIATIONS:** ACN-RF, anthocyanin-rich fraction; Cy-3-glc, cyanidin-3-glucoside; Dp-3-glc,
15 delphinidin-3-glucoside; GA, gallic acid; HUVEC, human umbilical vein endothelial cells; Mv-3-glc,
16 malvidin-3-glucoside; PrA, protocatechuic acid; SA, syringic acid; THP-1, human monocytic cells;
17 TNF- α , tumor necrosis factor-alpha; VCAM-1, vascular cell adhesion molecule-1.

18 **KEYWORDS:** anthocyanins; metabolites; E-selectin; VCAM-1; cell culture; atherogenesis

19

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22

23 **Abstract**

24 This study investigated the capacity of an anthocyanin-rich fraction (ACN-RF) from blueberry, single
25 anthocyanins (cyanidin, delphinidin and malvidin-3-glucoside; Cy, Dp and Mv-3-glc) and related
26 metabolites (protocatechuic, gallic and syringic acid; PrA, GA and SA) to resolve an inflammation-
27 driven adhesion of monocytes (THP-1) on endothelial cell (HUVECs) and secretion of cell adhesion
28 molecules E-selectin and vascular cell adhesion molecule 1 (VCAM-1).

29 The adhesion of THP-1 to HUVECs was induced by tumour necrosis factor α (TNF- α , 100 ng mL⁻¹).
30 Subsequently, ACN-RF, single ACNs and metabolites (from 0.01 to 10 μ g mL⁻¹) were incubated for
31 24 h. The adhesion was measured in a fluorescence spectrophotometer. E-selectin and VCAM-1 were
32 quantified by ELISA. No toxicological effects were observed for the compounds and the doses tested.
33 ACN-RF and Mv-3-glc reduced THP-1 adhesion at all the concentrations with the maximum effect at
34 10 μ g/ml (-60.2% for ACNs and -33.9% for Mv-3-glc). Cy-3-glc decreased the adhesion by about
35 41.8% at 10 μ g mL⁻¹, while PrA and GA reduced the adhesion of THP-1 to HUVECs both at 1 and
36 at 10 μ g mL⁻¹ (-29.5% and -44.3% for PrA, respectively, and -18.0% and -59.3% for GA,
37 respectively). At the same concentrations a significant reduction of E-selectin, but not VCAM-1
38 levels, was documented. No effect was observed following Dp-3-glc and SA supplementation.
39 Overall, ACNs and metabolites seem to resolve, in a dose-dependent manner, the inflammation-
40 driven adhesion of THP-1 to HUVECs by decreasing E-selectin concentrations. Interestingly, Mv-3-
41 glc was active at physiologically relevant concentrations.

42 **1. INTRODUCTION**

43 Anthocyanins (ACNs) are a group of abundant and widely consumed flavonoids providing the red,
44 blue, and violet colours in fruit- and vegetable-based food products. The dietary intake of ACNs is
45 up to 9-fold higher than that of other dietary flavonoids. Epidemiological studies have found an
46 inverse association between the consumption of ACNs and risk of cardiovascular diseases [1-6]. Their
47 role in prevention of cardiovascular disease is strongly linked to the protection against oxidative stress
48 and inflammation [7-10]. Atherosclerosis is the main underlying cause of cardiovascular disease in
49 humans. The early stage, i.e. atherogenesis, is characterized by activation of endothelial cells to
50 express cell adhesion molecules and recruit monocytes. This process is identical to the vascular
51 responses to tissue inflammation, which resolves when the underlying cause of inflammation (e.g. an
52 invading infectious agent) has been removed. However, the prolonged inflammatory milieu in early
53 atherosclerotic foci stimulates the transformation of monocytes foam cell [11].

54 It has been shown that ACNs prevent endothelial cell dysfunction by modulating the expression and
55 activity of several enzymes involved in nitric oxide production [12-13]. Furthermore, recent evidence
56 suggests that ACNs can down-regulate the expression of adhesion molecules and prevent the adhesion
57 of monocytes to endothelial cells challenged by pro-inflammatory cytokines [12;14]. The absorption
58 of ACNs is low (<1%), but most of them are rapidly transformed by human gut to metabolic products,
59 reaching a plasmatic concentration much higher than that of parental ACNs, indicating their
60 contribution in the biological activity observed should be considered [15]. We have reported that
61 ACNs and phenolic acid-rich fractions from a wild blueberry powder counteracted the adhesion of
62 monocyte to endothelial cells in a pro-inflammatory milieu [16]. In the same study, single ACNs and
63 certain gut metabolites (delphinidin-3-glc and gallic acid) prevented the attachment of monocytes to
64 endothelial cells, while malvidin-3-glc and syringic acid exacerbated the adhesion process [16].

65 In the present study, we investigated the capacity of the same ACNs to resolve an inflammatory
66 process by reducing the adhesion of monocytes to activated endothelial cells and the production of
67 vascular adhesion molecules as potential mechanisms in the atherogenesis. To this end, monocytic

68 (THP-1) cells were cultured with human umbilical endothelial cells (HUVECs) in the presence of the
69 pro-inflammatory cytokine tumour necrosis factor-alpha (TNF- α) to promote the expression of cell
70 adhesion molecules and interaction between the cells. TNF- α is produced by immune cells and it
71 stimulates endothelial cells to express adhesion molecules, including E-selectin, vascular cell
72 adhesion molecule-1 (VCAM-1) as well as chemokines (i.e. interleukin-8 and monocyte
73 chemoattractant protein-1) that promote the recruitment of monocytes to inflamed luminal
74 endothelium and induce their adhesion to endothelial cells at the site of activation [17]. The
75 expression of E-selectin occurs early following stimulation of pro-inflammatory cytokines such as
76 TNF- α in endothelial cells (4 and 6 h after stimulation and remains elevated up to 24 h) [18]. E-
77 selectin mediates the initial attachment of free-flowing leukocytes to the arterial wall, while the
78 expression of VCAM-1 provides a stronger interaction between leukocytes and endothelial cells and
79 mediates the transmigration of the cells into the tissue [18-19]. Cytokine-induced expression, and
80 subsequent down-regulation after cessation of exposure, in endothelial cells occurs later for VCAM-
81 1 than E-selectin [20]. We assessed the production of E-selectin and VCAM-1 to cover this “early”
82 and “late” phase of the endothelial production of cell adhesion proteins.

83 **2. MATERIALS AND METHODS**

84 **2.1 Reagents**

85 Standard of cyanidin, delphinidin and malvidin-3-glucoside (Cy, Dp and Mv-3-*O*-glc) were obtained
86 from Polyphenols Laboratory (Sandnes, Norway), while those of gallic, protocatechuic, and syringic
87 acid (GA, PrA and SA) from Sigma-Aldrich (St. Louis, MO, USA). Human Endothelial Cells Basal
88 Medium and Human Endothelial Cells Growth Supplement were purchased from Tebu-Bio
89 (Magenta, MI, Italy). Hanks balanced salt solution, foetal bovine serum (FBS), TNF- α were from
90 Sigma-Aldrich (St. Louis, MO, USA). Gentamicin, RPMI-1640, HEPES, Sodium Pyruvate, trypsin-
91 EDTA were from Life Technologies (Monza Brianza, MB, Italy) while the 5-
92 Chloromethylfluorescein Diacetate (CellTracker™ Green CMFDA) from Invitrogen (Carlsbad, CA,

93 USA).Hydrochloric acid and methanol were purchased from Merck (Darmstadt, Germany), while
94 water was obtained from a Milli-Q apparatus (Millipore, Milford, MA).

95 **2.2 Preparation and characterization of the ACN-rich fraction, single anthocyanins and** 96 **metabolites**

97 The extraction of the ACN-rich fraction from a wild blueberry powder (Future Ceuticals, Momence,
98 IL, USA)was performed as reported by Del Bo' et al. [16]. The fraction was characterized for the
99 content of ACNs, phenolic acids as well as other bioactives as previously published [16]. The total
100 ACN content was $45.11 \pm 0.35 \text{ mg mL}^{-1}$ and constituted predominantly of Mv-3-glc (about 26%),
101 Mv-3-gal (15%) followed by Dp-3-glc (9%) and Petunidin-3-glc (8%). No phenolic acids or other
102 bioactives were detectable.

103 Lyophilized standards of Mv, Cy, Dp-3-*O*-glc (native compounds) and SA, PrA and GA
104 (corresponding metabolites) are shown in **Figure 1**. The standards were prepared as previously
105 reported [16]. These single compounds were tested since found in the blood stream of volunteers after
106 consumption of a blueberry portion [21].

107 **2.3 Cell culture and viability**

108 Human umbilical vein endothelial cells (HUVECs; Tebu-Bio SrL, Magenta, MI, Italy) were cultured
109 in endothelial cell growth medium kit containing 2% serum at 37°C and 5% CO₂ until reaching
110 confluence (generally after 1 week). THP-1 cells were grown in a complete RPMI cell media (RPMI-
111 1640 medium supplemented with 1% HEPES, 1% sodium pyruvate, 0.1% gentamicin, and 10% FBS
112 at 37 °C and 5% CO₂ and maintained in culture for up to 3 months.

113 Cell viability was performed for each compound and concentration by Trypan blue and (3-(4,5-
114 dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay, showing cells viability above
115 90% as previously published [16].

116 **2.4 THP-1 adhesion to HUVECs**

117 An aliquot of 2×10^4 HUVECs was seeded on 0.1% gelatine pre-coated 96-well black plate and
118 maintained at 37°C and 5% CO₂ for 24h.Subsequently, monocytic (2×10^6) THP-1 cells (American

119 Type Culture Collection, Manassas, VA, USA) were re-suspended in 1 mL serum free RPMI cell
120 medium (containing 1% HEPES, 1% sodium pyruvate, 0.1% gentamicin) and labelled with
121 CellTracker™ Green CMFDA (1 μ M, 30 min at 37°C and 5% CO₂). THP-1 were washed twice, re-
122 suspended in HUVEC medium (2x10⁵ cells mL⁻¹density) and added to HUVECs with TNF- α (100
123 ng mL⁻¹). After 24 h incubation (37°C, 5% CO₂) medium was removed and 200 μ L of new medium,
124 containing the single ACNs (Mv, Cy and Dp-3-glucoside) and their corresponding metabolites (SA,
125 PrA and GA, respectively) was added at the concentrations of 0.01, 0.1, 1 and 10 μ g mL⁻¹ for 24 h at
126 37°C and 5% CO₂. Then, media was collected and stored at -80°C until analysis. Cells were rinsed
127 twice before the measure of the fluorescence (excitation: 485 nm, emission: 538 nm; mod. F200
128 Infinite, TECAN Milan, Italy). The level of fluorescence is associated with the number of labeled-
129 THP-1 cells attached to the HUVECs. The results derive from three independent experiments in
130 which each concentration was tested in quintuplicate. Data are reported as fold increase compared to
131 the control cells without stimulation with TNF- α or bioactive compounds.

132 **2.5 Visualization at the microscope**

133
134 The adhesion of THP-1 to HUVECs was visualized at the microscope. HUVEC (4x10⁴/well) were
135 seeded onto 0.1 % gelatin pre-coated 12-well plate for 24 h. THP-1 (8x10⁴/well) were stained with
136 CellTracker™ Green CMFDA and added with TNF- α to HUVECs as previously reported. After
137 treatment, cells were rinsed with Hank solution in order to remove the non adherent cells and
138 inspected with an inverted wide-field microscope with 10 \times magnifications.

139 140 **2.6 Determination of soluble VCAM-1 and E-selectin concentration in cell supernatant**

141 The concentrations of soluble VCAM-1 and E-selectin, in recovered cell culture supernatants, were
142 quantified by ELISA kits according to the manufacture's instruction. The analyses were conducted
143 in quadruplicate and the results derived from three independent experiments.

144 **2.7 Statistical analysis**

145 One-way ANOVA was applied to verify the effect of the different concentrations of ACNs and
146 metabolites on fold increase THP-1 adhesion to HUVECs and on percentage changes in soluble
147 VCAM-1 and E-selectin concentration. Differences between treatments was assessed by the Least
148 Significant Difference (LSD) test with $p < 0.05$ as level of statistical significance. Results are reported
149 as mean \pm standard error of mean. The statistical analysis was performed by means of STATISTICA
150 software (Statsoft Inc., Tulsa, OK, USA).

151

152 **3. RESULTS**

153 **3.1 Effect of ACN-rich fraction on monocytes adhesion process**

154 In **Figure 2** are reported the effects of ACN-RF on THP-1 adhesion to HUVECs. There was a
155 significant increase in THP-1 cell adhesion to HUVECs following stimulation with TNF- α
156 ($p < 0.0001$), while the incubation with ACN-RF significant reduced the process ($p < 0.0001$) at all the
157 concentrations tested (from 0.01 to 10 $\mu\text{g mL}^{-1}$). The maximum effect of reduction was observed at
158 10 $\mu\text{g mL}^{-1}$ (-60.2%) with respect to the control with TNF- α .

159

160 **3.2 Effect of anthocyanins and metabolic products on monocytes adhesion process**

161 **Figure 3 (A-C)** shows the results on THP-1 adhesion to HUVECs after incubation with the single
162 ACNs. The incubation with Mv-3-glc significantly decreased ($p < 0.0001$) the adhesion of monocytes
163 to HUVECs at all the concentrations tested (from 0.01 to 10 $\mu\text{g mL}^{-1}$) compared to TNF- α (**Fig. 3A**).
164 The maximum reduction was observed for the concentration at 10 $\mu\text{g mL}^{-1}$ (-33.9%; $p < 0.0001$) as
165 also reported in **Figure 4** that shows the adhesion of labelled THP-1 to endothelial cells following 24
166 h stimulation with TNF- α (A), TNF- α + 10 $\mu\text{g/mL}$ Mv-3-glc (B) and control (C). Regarding Cy-3-
167 glc, a significant reduction in the adhesion of THP-1 to HUVEC was observed only at 10 $\mu\text{g mL}^{-1}$ (-
168 41.8%; $p < 0.01$) (**Fig. 3B**), while no significant effect was found for Dp-3-glc (**Fig. 3C**).

169 **Figure 5 (A-C)** reports the results on THP-1 adhesion to HUVECs after incubation with SA, PrA and
170 GA (metabolites of Mv-3-glc, Cy-3-glc, and Dp-3-glc, respectively). No significant effect was

171 observed following SA supplementation (**Fig. 5A**) in line with the results reported in **Fig. 4** that shows
172 the adhesion of labelled THP-1 to endothelial cells following stimulation with TNF- α + 10 $\mu\text{g}/\text{mL}$
173 SA (D). The supplementation with PrA (**Fig. 5B**) and GA (**Fig. 5C**) significantly decreased the
174 adhesion of monocytes to endothelial cells at 1 $\mu\text{g mL}^{-1}$ (-18.0%; $p < 0.05$ for GA, -29.5%; $p < 0.05$ for
175 PrA) and 10 $\mu\text{g mL}^{-1}$ (-59.3%; $p < 0.001$ for GA, -44.3%; $p < 0.01$ for PrA) compared to TNF- α .

176 **3.3 Effect of anthocyanins and metabolic products on soluble E-selectin and VCAM-1 levels in** 177 **cell supernatant**

178 **Table 1** shows the levels of E-selectin quantified in the cell supernatant following incubation with
179 ACNs and metabolites. There was a significant increase in E-selectin following stimulation with
180 TNF- α compared to negative control (without TNF- α). The incubation of cells with Mv-3-glc
181 significantly reduced ($p < 0.001$) the levels of E-selectin at all concentrations tested. This reduction
182 was not concentration dependent and the maximum effect was observed at 0.01 and 0.1 $\mu\text{g mL}^{-1}$ (-
183 66% and -67%, respectively). Cy-3-glc reduced the E-selectin concentration at 10 $\mu\text{g mL}^{-1}$ (-72%;
184 $p < 0.01$), PrA at 1 and 10 $\mu\text{g mL}^{-1}$ (-74 and -76%; $p < 0.001$, respectively), and GA at 1 $\mu\text{g mL}^{-1}$ (-34%;
185 $p < 0.01$) and 10 $\mu\text{g mL}^{-1}$ (-40%; $p < 0.01$). No effect was found after Dp-3-glc and SA incubation in
186 line with the lack of the positive effect on the adhesion of THP-1 to HUVECs.

187 The levels of VCAM-1 quantified in the cell supernatant following incubation with ACNs and
188 metabolites are reported in **Table 2**. There was a significant increase ($p < 0.05$) following stimulation
189 with TNF- α compared to negative control (without TNF- α). However, no significant effect was
190 observed following incubation with ACNs and gut metabolites.

191

192 **4. DISCUSSION**

193 Chronic inflammation is a common factor in endothelial dysfunction and atherosclerosis
194 [11;22]. Different cell models have been used to assess the interaction between endothelial cells and
195 monocytic cell lines (e.g. THP-1, U937, MonoMAC) or freshly isolated leukocytes as early event in

196 atherosclerosis. We obtained a two-fold increase in attachment of THP-1 cells to HUVECs which is
197 in line with earlier observations with the same co-culture [23-24]). The TNF-induced attachment of
198 monocytic U937 cells to endothelial cells seems to be in the range of a 2-3-fold increase [25-26],
199 whereas MonoMAC cells may have higher sensitivity and response to TNF-mediated adhesion to
200 HUVECs (i.e. 6-fold increase at 10 $\mu\text{g}/\text{mL}$ TNF- α) [27] Poussin 2014).

201 In the last years, several studies have focused on the mechanisms through which polyphenols
202 modulate the adhesion process and the vascular inflammation [28-29]. Here we evaluated the capacity
203 of Mv, Cy, and Dp-3-glc, and corresponding metabolites, to resolve an inflammation-driven adhesion
204 of THP-1 to HUVECs and the production of vascular adhesion molecules. The results obtained
205 documented that ACN-RF and Mv-3-glc had an effect at all the concentrations tested, while Cy-3-
206 glc, GA and PrA resolved the adhesion process only at the high concentrations (1 and 10 $\mu\text{g mL}^{-1}$).
207 These findings are in contrast with those documented in a previous experiment, in which Mv-3-glc
208 led to an exacerbation of the adhesion process, while Cy and PrA failed to affect the interaction
209 between monocytes and endothelial cells [16]. In light of our results, we hypothesize that these
210 compounds are more active in resolving than preventing the adhesion process. *In vitro* studies
211 reported a beneficial effect on the prevention of atherogenesis only at supra-physiological
212 concentrations in according with our findings [25-33]. However, recent *in vitro* studies showed a
213 positive effect of ACNs, phenolic acids and gut metabolites also at physiological relevant
214 concentrations [34-35]. For example, Kraga et al., [35] reported that Cy-3-glucoside, galattoside and
215 arabinoside, as well as Dp and Peondin-3-glucoside and phenolic acids/gut metabolites (vanillic acid,
216 ferulic acid, hippuric acid, 4-hydroxybenzaldehyde and PrA) decreased the adhesion of monocytes to
217 HUVECs from 0.1 to 2 μM . The effect was also confirmed when ACNs and phenolic acids were used
218 as a mix, suggesting an additive effect of the compounds.

219 In our experimental conditions, the reduction of adhesion of THP-1 to TNF- α -activated
220 HUVECs after supplementation with ACNs and metabolites can be attributed to different non-
221 specific and/or specific complex mechanisms of action. Further insight into the mechanisms can be

222 gained by high content screening and transcriptomics of inflammatory and oxidative stress pathways
223 as used in co-culture studies of monocytes and HUVECs [36]. Inhibition of NF- κ B activity could
224 have reduced the synthesis of numerous cytokines by decreasing the levels of inflammation at
225 endothelial level. In this regard, the inhibition of pro-inflammatory cytokines such as TNF- α and the
226 reduction of leukocyte adhesion to endothelial cells are key mechanisms in the control of
227 atherogenesis and atherosclerosis. Moreover, ACNs have a pivotal role in the modulation of mitogen-
228 activated protein kinase pathways implicated in several cellular processes including proliferation,
229 differentiation, apoptosis, cell survival, cell motility, metabolism, stress response and inflammation
230 [8]. Alternatively, the use of ACNs and phenolic acids may repress the secretion of chemokine (C-C
231 motif) ligand 2 (MCP-1), which pilots the migration of monocytes toward the intracellular cleft
232 between adjacent endothelial cells, or reduce the production of adhesion molecules such as VCAM-
233 1, ICAM-1 and E-selectin that regulate the recruitment of monocytes into atherosclerosis-prone area.
234 In our experimental conditions, we found that the alleviating effects on cell adhesion, induced by the
235 single compounds, were associated with changes in the levels of E-selectin, but not VCAM-1 levels.
236 We found that Mv-3-glc was more effective in reducing the production of E-selectin compared to the
237 other compounds tested. In fact, the decrease was observed both at low and high concentrations, while
238 for Cy-3-glc, PrA and GA the effects were detected only at the high doses. The increased E-selectin
239 production at high concentration may be due to a stimulation of the cells as also shown in a previous
240 study where Mv-glc led to an exacerbation of the adhesion process [16]. Dp-3-glc and SA
241 supplementation did not show any reduction in line with the lack of an effect on THP-1 adhesion to
242 HUVECs. Conversely, different studies report changes in the expression/levels of VCAM-1, ICAM-
243 1, other than E-selectin, following ACNs and metabolites supplementation; most of them showed a
244 beneficial effect only at supra-physiological concentrations. For example, Ferrari et al., [38]
245 demonstrated that Cy-3-glc (20 μ M) counteracted the acute pro-inflammatory effects of TNF- α in
246 HUVECs, reduced leukocyte recruitment from microcirculation, and decreased the gene expression
247 levels of E-selectin and VCAM-1. Huang et al., [39] reported that the supplementation with different

248 concentrations of Mv-3-glc (1-100 μ M) inhibited the TNF- α -induced inflammatory response in a
249 concentration-dependent manner and reduced the production of MCP-1, ICAM-1 and VCAM-1 in
250 endothelial cells. Nizamutdinova and colleagues [40] found that ACNs from black soybean seed coats
251 (rich in Cy, Dp and Petunidin-3-glucoside) reduced TNF- α -mediated VCAM-1 induction in a
252 concentration-dependent manner (10, 50, and 100 μ g/mL), but not ICAM-1 in HUVEC. Amin et al.,
253 [41] showed that simulated human vascular endothelial cells with oxidized-LDL and co-treated with
254 Cy-3-glc (0.1, 1, and 10 μ M concentrations) significantly reduced VCAM-1 protein production. In
255 addition, phenolic acids affected the expression and the levels of adhesion molecules. Warner et al.,
256 [42] tested the capacity of 20 different phenolic acids to reduce the secretion of VCAM-1 in activated
257 TNF- α endothelial cells showing a significant effect for PrA in a concentration-dependent manner (1-
258 100 μ M). Similar results were also found following vanillic, isovanillic, ferulic, hyppuric acids and
259 derivatives supplementation [37;41-42].

260

261 **5. CONCLUSIONS**

262 In conclusion, this study documented the capacity of Mv-3-glc, Cy-3-glc, PrA and GA to reverse an
263 atherogenic condition. This reduction can be explained by a significant decrease in the adhesion of
264 monocytes to endothelial cells and in the production of E-selectin, but not VCAM-1 in the present
265 short-term incubation period. Mv-3-glc seems the most potent anti-atherogenic compound since it
266 activates both at supraphysiological and physiological concentrations.

267

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277

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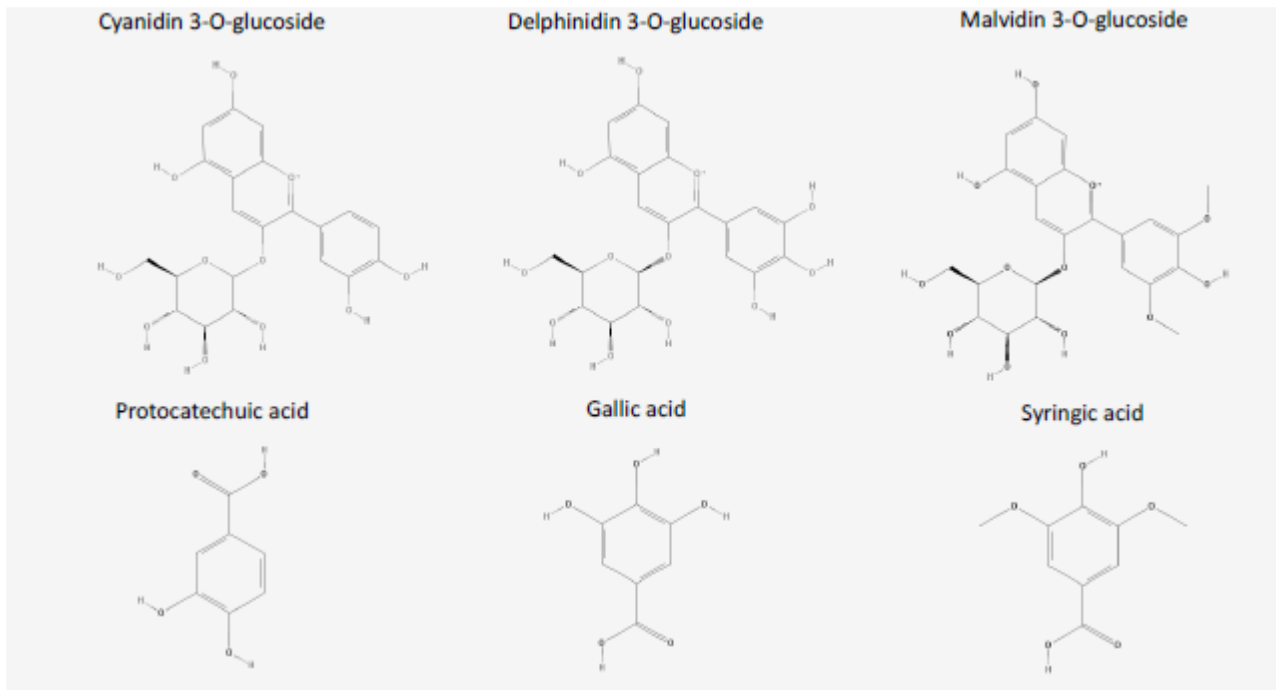
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395

396 **FIGURE CAPTION**

397 **Figure 1-** Chemical structure of anthocyanins and their metabolites used in this study
398



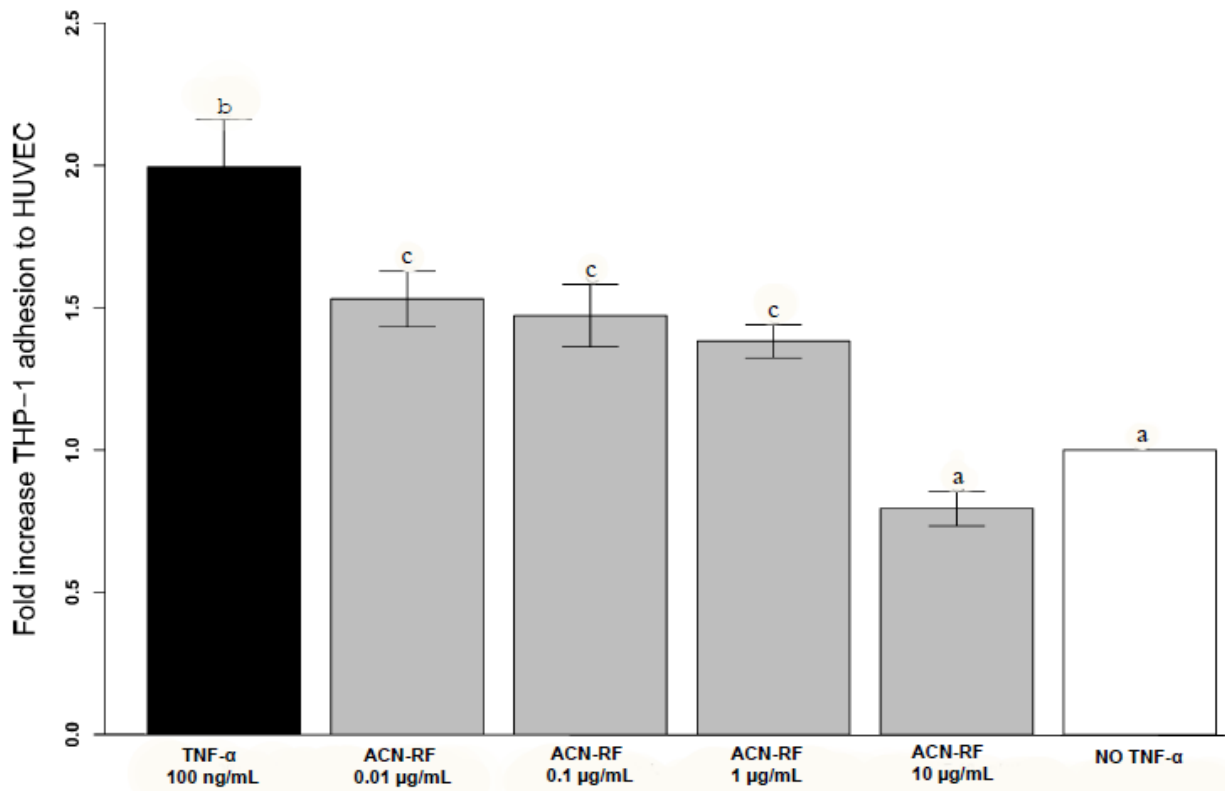
399

400 **Legend:** *Mv-3-glc*, malvidin-3-glucoside; *Cy-3-glc*, cyanidin-3-glucoside; *Dp-3-glc*, delphinidin-3-
401 glc; *SA*, syringic acid; *PrA*, protocatechuic acid; *GA*, gallic acid;

402

403 **Figure 2-** Effect of *ACN-RF* (0.02 and 18.9 μM , expressed as *Mv-3-glc* as the main compound) on
404 THP-1 adhesion to HUVECs. Results are expressed as mean \pm standard error of mean. ^{a,b,c}Bar graphs
405 reporting different letters are significantly different ($p \leq 0.05$).

Figure 2



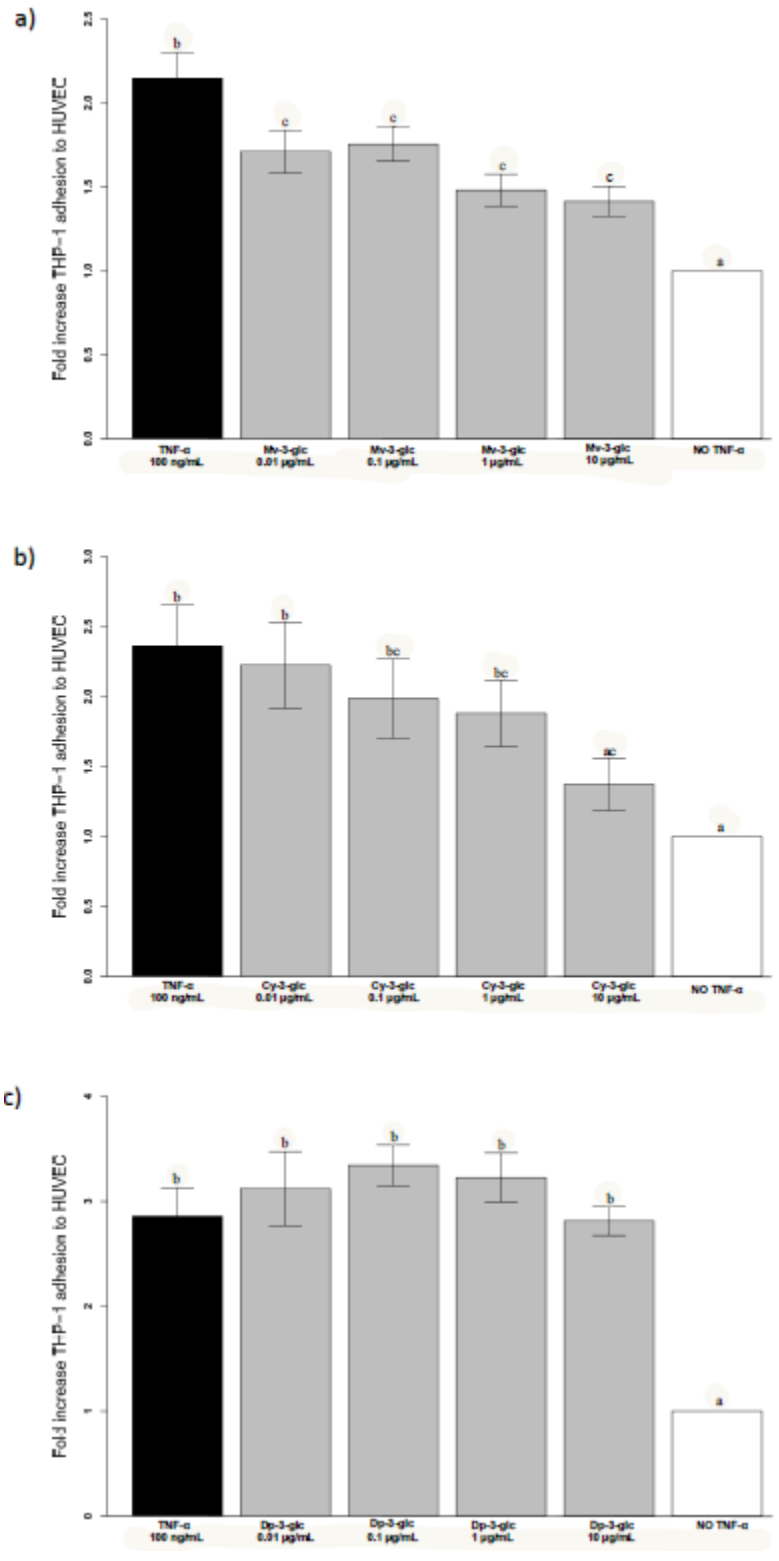
406

407 **Legend:** *TNF- α* tumor necrosis factor alpha, *ACN-RF* anthocyanin-rich fraction, *NO TNF- α* (control).

408

409

410 **Figure 3-** Effect of **A)** *Mv-3-glc* (0.02–18.9 μ M), **B)** *Cy-3-glc* (0.03–25.9 μ M) and **C)** *Dp-3-glc* (0.02–
 411 19.9 μ M) on THP-1 adhesion to HUVECs. Results are expressed as mean \pm standard error of mean.
 412 ^{a,b,c}Bar graphs reporting different letters are significantly different ($p \leq 0.05$).

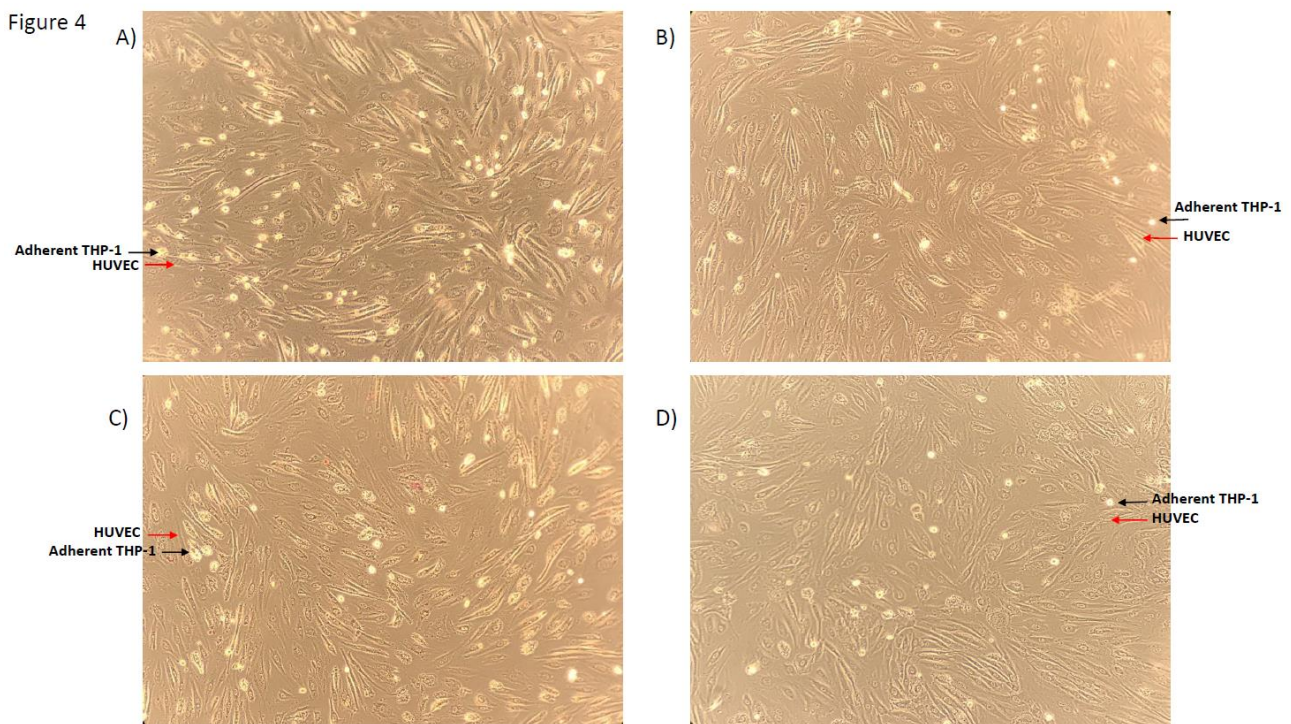


413

414 **Legend:** *TNF- α* , tumor necrosis factor alpha; *Mv-3-glc*, malvidin-3-glucoside; *Cy-3-glc*, cyanidin-
415 3-glucoside; *Dp-3-glc*, delphinidin-3-glc; *NO TNF- α* (control).

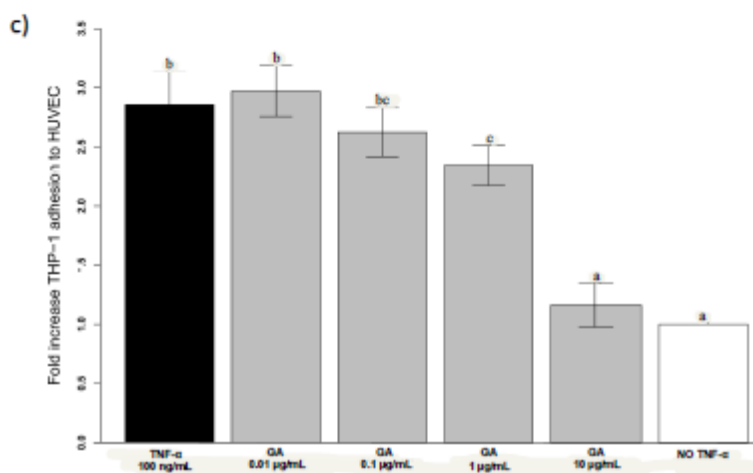
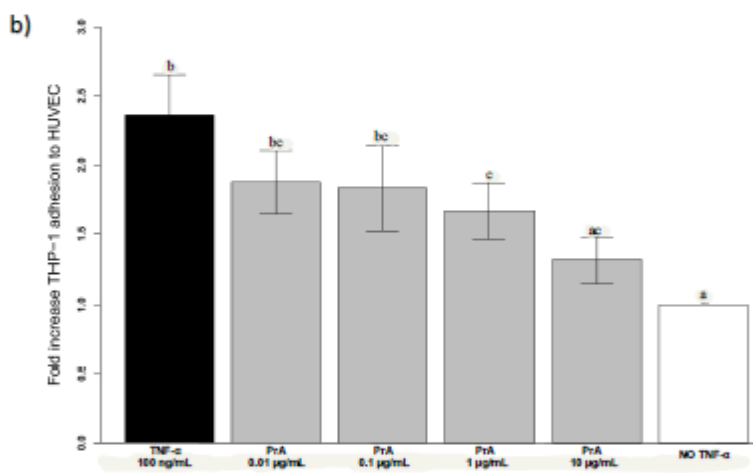
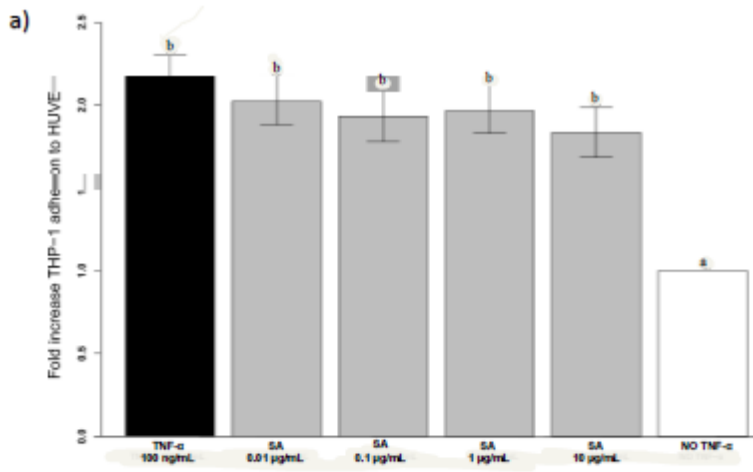
416 **Figure 4** Visualization of THP-1 adhesion to HUVEC following 100 ng mL⁻¹ of TNF- α (a), TNF- α
417 +10 μ g mL⁻¹ of *Mv-3-glc* (b), TNF- α + 10 μ g mL⁻¹ of SA (c), and NO TNF- α (d).

418 **Legend:** *TNF- α* , tumor necrosis factor alpha; *Mv-3-glc*, malvidin-3-glucoside; SA, syringic acid; *NO*
419 *TNF- α* (control). Round yellow cells represent THP-1 cells adhered to HUVECs. The black arrows
420 indicate an example of adhered THP-1, while the red arrows indicate HUVECs.



421

422 **Figure 5-** Effect of **A)** SA (0.05-50.5 μ M), **B)** *PrA*(0.03–64.9 μ M) and **C)** GA (0.03–58.8 μ M) on
423 THP-1 adhesion to HUVECs. Results are expressed as mean \pm standard error of mean. ^{a,b,c}Bar graphs
424 reporting different letters are significantly different ($p \leq 0.05$).



425

426 **Legend:** *TNF- α* , tumor necrosis factor alpha; *SA*, syringic acid; *PrA*, protocatechuic acid; *GA*, gallic
 427 acid; *NO TNF- α* (control).

428 **Table 1: Effect of ACNs and metabolites on the levels of E-selectin**

Concentrations	Compounds					
	Mv-3-glc	Cy-3-glc	Dp-3-glc	SA	PrA	GA
0.01 $\mu\text{g mL}^{-1}$	107 \pm 15 ^a	311 \pm 13 ^a	308 \pm 11 ^a	299 \pm 15 ^a	290 \pm 13 ^a	304 \pm 15 ^a
0.1 $\mu\text{g mL}^{-1}$	104 \pm 16 ^a	297 \pm 15 ^a	299 \pm 22 ^a	297 \pm 15 ^a	257 \pm 12 ^a	321 \pm 11 ^a
1 $\mu\text{g mL}^{-1}$	186 \pm 12 ^a	300 \pm 14 ^a	295 \pm 12 ^a	297 \pm 16 ^a	83 \pm 15 ^b	206 \pm 10 ^b
10 $\mu\text{g mL}^{-1}$	149 \pm 24 ^a	83 \pm 10 ^b	315 \pm 16 ^a	295 \pm 14 ^a	74 \pm 18 ^b	188 \pm 17 ^b
(TNF- α) 100 ng mL ⁻¹	316 \pm 16 ^b	307 \pm 11 ^a	318 \pm 12 ^a	316 \pm 16 ^a	307 \pm 11 ^a	318 \pm 12 ^a
(TNF- α) 0 ng mL ⁻¹	59 \pm 9.0 ^c	64 \pm 10 ^c	65 \pm 4.6 ^b	59 \pm 9.0 ^b	64 \pm 10 ^c	65 \pm 4.6 ^c

429

430 Data derived from three different experiments and each concentration tested in triplicate. Each ACN and metabolite was tested in presence of TNF- α stimulus. Results are expressed

431 as mean \pm SEM. *Mv-3-glc*, malvidin-3-glucoside; *Cy-3-glc*, cyanidin-3- glucoside, *Dp-3-glc*, delphinidin-3-glc; *SA*, syringic acid, *PrA*, protocatechuic acid; *GA*, gallic acid; *TNF- α* ,

432 tumor necrosis factor alpha. ^{a,b,c}Data with different letters are significantly different ($p < 0.05$). Concentration range: 0.02-18.9 μM for *Mv-3-glc*, 0.02-19.9 μM for *Dp-3-glc*, 0.02-

433 20.6 μM for *Cy-3-glc*, 0.25 and 50.5 μM for *SA*, 0.32-64.9 μM for *PrA* and 0.29-58.8 μM for *GA*.

434

435 **Table 2: Effect of ACNs and metabolites on the levels of VCAM-1**

Concentrations	Compounds					
	Mv-3-glc	Cy-3-glc	Dp-3-glc	SA	PrA	GA
0.01 $\mu\text{g mL}^{-1}$	13.16 \pm 0.78	15.10 \pm 0.35	15.98 \pm 0.76	15.43 \pm 0.41	14.38 \pm 0.17	16.98 \pm 1.76
0.1 $\mu\text{g mL}^{-1}$	13.64 \pm 0.04	14.56 \pm 0.23	15.80 \pm 1.10	16.59 \pm 0.28	14.83 \pm 0.53	14.99 \pm 1.90
1 $\mu\text{g mL}^{-1}$	14.15 \pm 0.33	14.65 \pm 0.20	16.94 \pm 0.51	18.85 \pm 0.23	15.28 \pm 0.42	16.64 \pm 0.71
10 $\mu\text{g mL}^{-1}$	14.38 \pm 0.11	15.10 \pm 0.24	16.30 \pm 0.40	17.45 \pm 0.29	16.19 \pm 0.37	16.26 \pm 0.80
(TNF- α) 100 ng mL ⁻¹	15.74 \pm 1.14	15.17 \pm 1.08	16.97 \pm 1.81	15.74 \pm 1.14	15.17 \pm 1.08	16.97 \pm 1.81
(TNF- α) 0 ng mL ⁻¹	11.04 \pm 0.37 [*]	10.99 \pm 0.35 [*]	11.27 \pm 0.28 [*]	11.04 \pm 0.37 [*]	10.99 \pm 0.35 [*]	11.27 \pm 0.28 [*]

436

437 Data derived from three different experiments and each concentration tested in triplicate. Each ACN and metabolite was tested in presence of TNF- α stimulus. Results are expressed

438 as mean \pm SEM. *Mv-3-glc*, malvidin-3-glucoside; *Cy-3-glc*, cyanidin-3- glucoside, *Dp-3-glc*, delphinidin-3-glc; *SA*, syringic acid, *PrA*, protocatechuic acid; *GA*, gallic acid; *TNF-*

439 α , tumor necrosis factor alpha. ^{*}Significantly different ($p < 0.05$). Concentration range: 0.02-18.9 μM for *Mv-3-glc*, 0.02-19.9 μM for *Dp-3-glc*, 0.02-20.6 μM for *Cy-3-glc*, 0.25

440 and 50.5 μM for *SA*, 0.32-64.9 μM for *PrA* and 0.29-58.8 μM for *GA*.