Biological Activity of Anthocyanins

2018 IACM Global Color Conference

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Overview

- Natural pigments: generalities
- Technological properties of anthocyanins as food pigments
- Anthocyanins: potential health benefits

Natural pigments

- Naturally-occurring compounds that absorb light at certain wavelengths
- Responsible for imparting colors of foods
- Differ in solubility
  - Water-soluble: anthocyanins
  - Water-insoluble: chlorophyll and carotenoids

Natural pigments

Food color industry trends

FoodOnline | SAFE PROCESSING AND PACKAGING

Shaped By Consumer Trends, Food Color Market Will Grow To $2.3 Billion Industry By 2019

The world's true measure of color HunterLab

Color Additives: Adjusting to Changing Trends with Natural Alternatives

BusinessWire
A Berkshire Hathaway Company

US Food Colorants Market Report 2016 - $2.5 Billion Growth, Trends and Forecasts (2015-2020) - Research and Markets

RESEARCHANDMARKETS
THE WORLD'S LARGEST MARKET RESEARCH STORE

The North American food & beverage colorants market is estimated to grow at CAGR of 4.6% in the period between 2015 and 2020

FOODBUSINESSNEWS
Colors trends twist to natural

FOOD PROCESSING
The Information Source for Food and Beverage Manufacturers

Food Colorant Trends Show Natural is Critical for Consumers

Color manufacturers are following the "natural" trend by working closely with food, beverage and drug manufacturers to create and stabilize colors derived from natural sources.

FOOD navigator.com

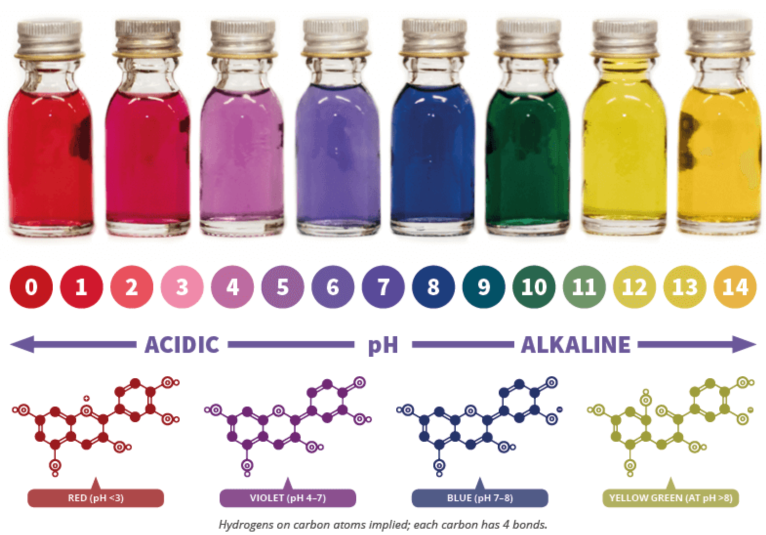
Natural and organic trends drive European food colourings growth

Anthocyanins: natural pigments

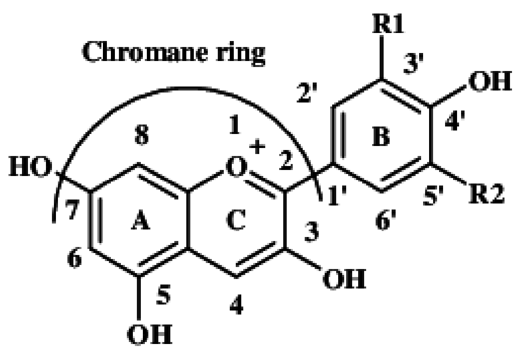
- Water-soluble pigments responsible for the pink, red, blue, and violet colors of flowers, fruits and vegetables

- Anthocyanins: Anthocyanidins conjugated with sugar

- Color depends on pH

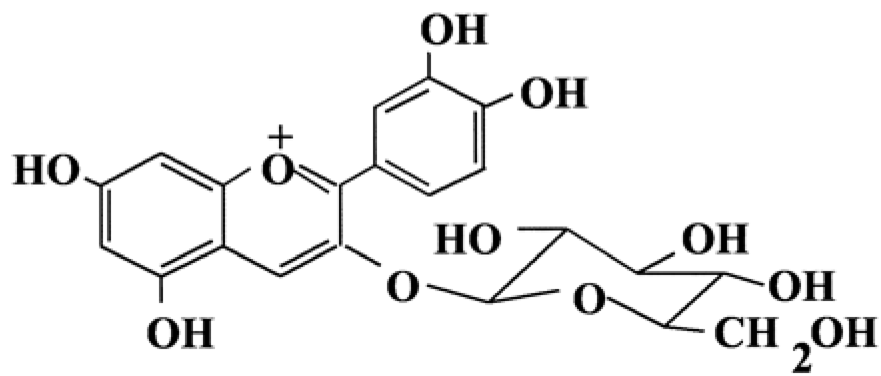


Anthocyanin structure



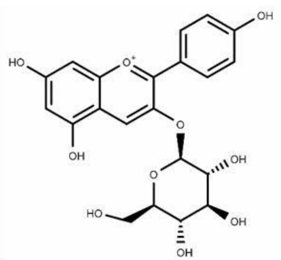
Aglycone	R1	R2	colour	λ_{max} (nm)
Cyanidin (Cy)	OH	H	Red	535
Peonidin (Pn)	OCH3	H	Bluish-purple	532
Pelargonidin (Pg)	H	H	Orange-red	520
Malvidin (Mv)	OCH3	OCH3	Purple	542
Delphinidin (Dp)	OH	OH	Purple	546
Petunidin (Pt)	OCH3	OH	Purple	543

Sugar groups:
- Glucose
- Sambubiose
- Rutinose
- Sophorose



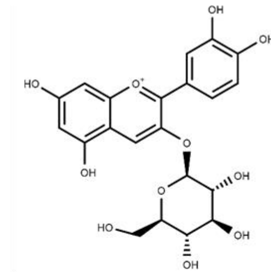
Cyanidin 3-*O*-β-D-glucoside

Most abundant anthocyanins in foods and examples of sources



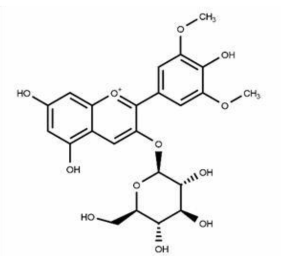
Pelargonidin-3-*O*-glucoside

Cranberries: 49.16 mg peonidin/100g



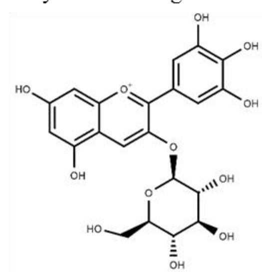
Cyanidin-3-*O*-glucoside

Illawara plum: 555.72 mg cyanidin/100g



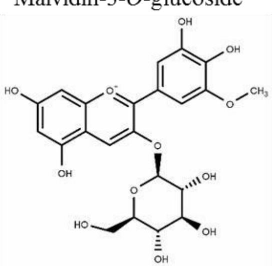
Malvidin-3-*O*-glucoside

Red shiraz: 121.65 mg malvidin/100g



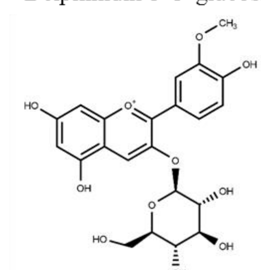
Delphinidin-3-*O*-glucoside

Bilberry: 97.59 mg delphinidin/100g



Petunidin-3-*O*-glucoside

Black beans: 15.41 mg petunidin/100g



Peonidin-3-*O*-glucoside

Radishes: 63.13 mg pelargonidin/100g

Mazewski & de Mejia. 2018. 'Impact of anthocyanins on colorectal cancer. 'In: Advances in Plant Phenolics: From Chemistry to Human Health. American Chemical Society .Symposium Series #1286, Chapter 19, 339-370.

Other plant sources of anthocyanins

Fruits

Purple grape

Red grape

Vegetables

Purple Sweet Potato

Purple Carrot

Legumes

Black bean

Purple bean

Black lentils

Black peanut

Cereals

Sorghum

Black rice

Blue wheat

Dietary anthocyanin sources

- Relative abundance of anthocyanin from plants is variable:
  - genetic and agronomic variation
  - light intensity and type
  - temperature
  - harvest time, storage, and processing condition

- Data on food anthocyanins composition and concentration are limited and debated

- Regardless of the variation of anthocyanin concentration in food, it is necessary to establish standardized databases

Azzini *et al.*, 2017. Ox Med Cell Long, Article ID 2740364

Applications of anthocyanins: food colorants

Anthocyanins are of interest to **food scientists** because:

- they can be used as color **additives** in food preparations.
- they are not stable during food processing affecting color and biological value.

Anthocyanins as food colorants

Cream cheese

Jelly

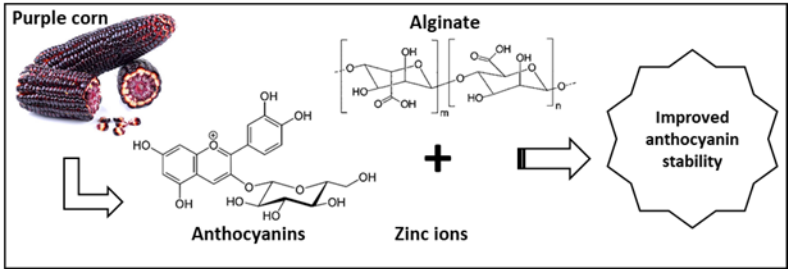
Low-pH beverage

- Advantages: lower environmental impact, no toxicity, beneficial effects for human health
- Disadvantages: expensive processing, current sources are inefficient and wasteful, producing byproducts with little or no value

- Dia et al., 2015. *J Agric. Food Chem*. 63, 3205–3218.
- De Mejia et al., 2015. *J Agric Food Chem*. 63, 10032–10041.
- Li et al., 2017. *Food Chem*. 231, 332–339
- Luna-Vital et al., 2017. *Food Chem*. 232, 639–647.
- Haggard et al., 2018. *Food Res Int*. 105, 286-297.

There are several strategies to stabilize anthocyanins

- Polymeric compounds as copigments
- Polyphenolic compounds with stabilizing effect (for example, Rosemary extract)
- Metallic ions
- -SH group-containing compounds
- Controlled atmospheres
- Spray drying
- Freeze-drying
- Encapsulation
- Genetic modification of crops: gene-encoded acyltransferase or aromatic acyl groups

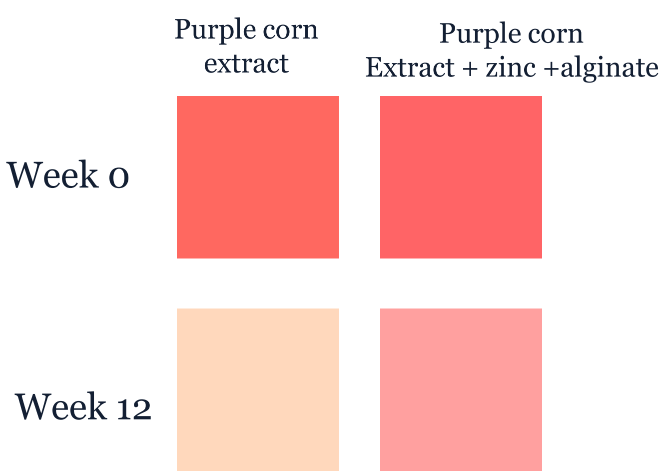


Cortez *et al.*, 2017. Comp Rev Food Sci Food Safety, 16(1): 180-198

Zinc and alginate increased the stability of anthocyanins from purple corn in a beverage model

+

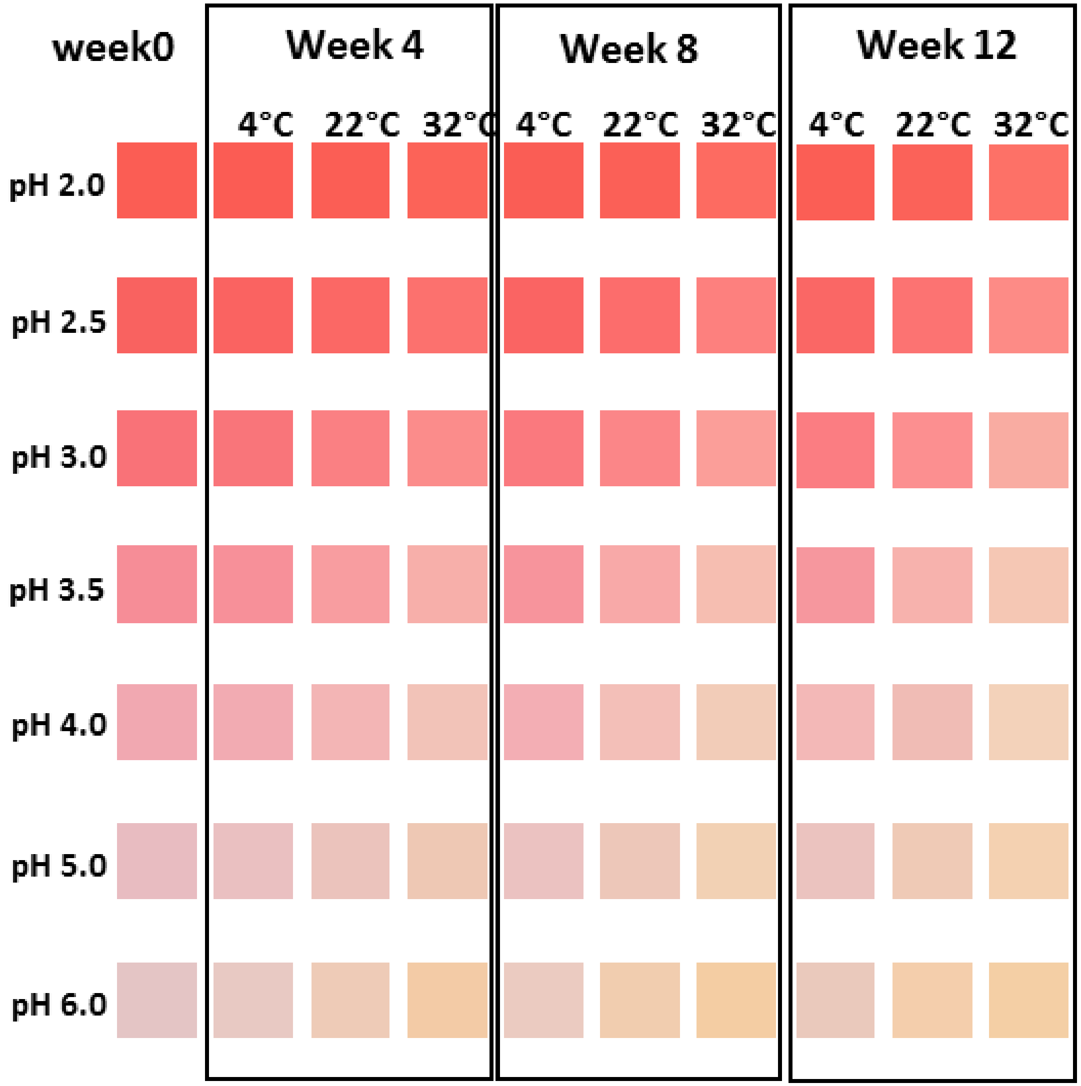
+ Zinc + Alginate



Beverage model using anthocyanins from purple corn and the combination of zinc and alginate.

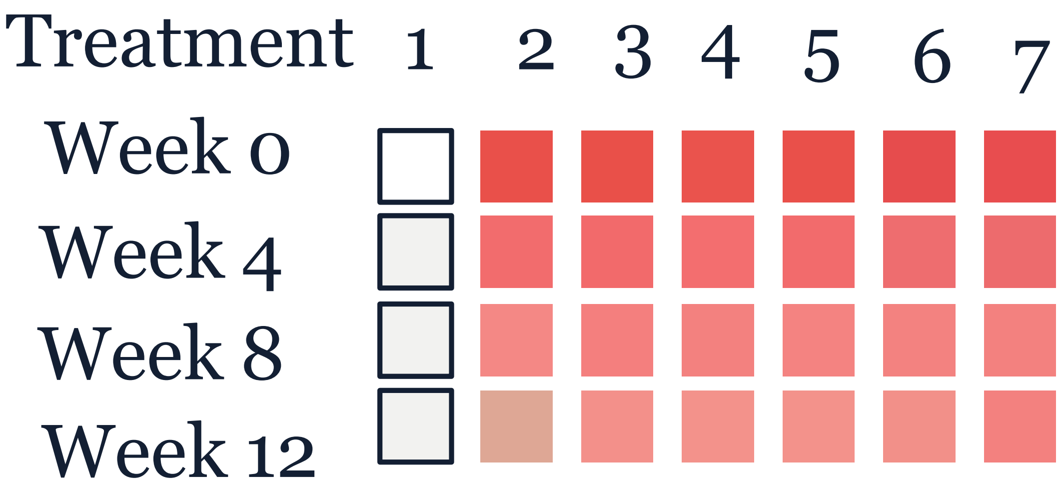
Luna-Vital et al. (2017) Protection of color and chemical degradation of anthocyanin from purple corn (*Zea mays* L.) by zinc ions and alginate through chemical interaction in a beverage model. *Food Research International*, 105, 169-177.

pH and temperature have an important effect in anthocyanins



Luna-Vital *et al.*, 2017. Food Chem. 13(7), 232: 6396-647

Zinc and alginate helps promoting the stability of anthocyanins from colored corn (PCW)



	Treatment
T1	Kool Aid invisible
T2	PCW
T3	0.2 mM $ZnCl_2$
T4	0.4 mM $ZnCl_2$
T5	0.4 % alginate (AA)
T6	0.2 mM $ZnCl_2$ + AA
T7	0.4 mM $ZnCl_2$ +AA

- ✓ Zinc and alginate protected corn anthocyanins from degradation in a beverage model
- ✓ Zinc and alginate combined improved the stability of color parameters in a beverage
- ✓ The protective mechanism relies on the interaction of anthocyanins with zinc and alginate

Luna-Vital *et al.*, 2017. Food Res Int. 105: 169-177

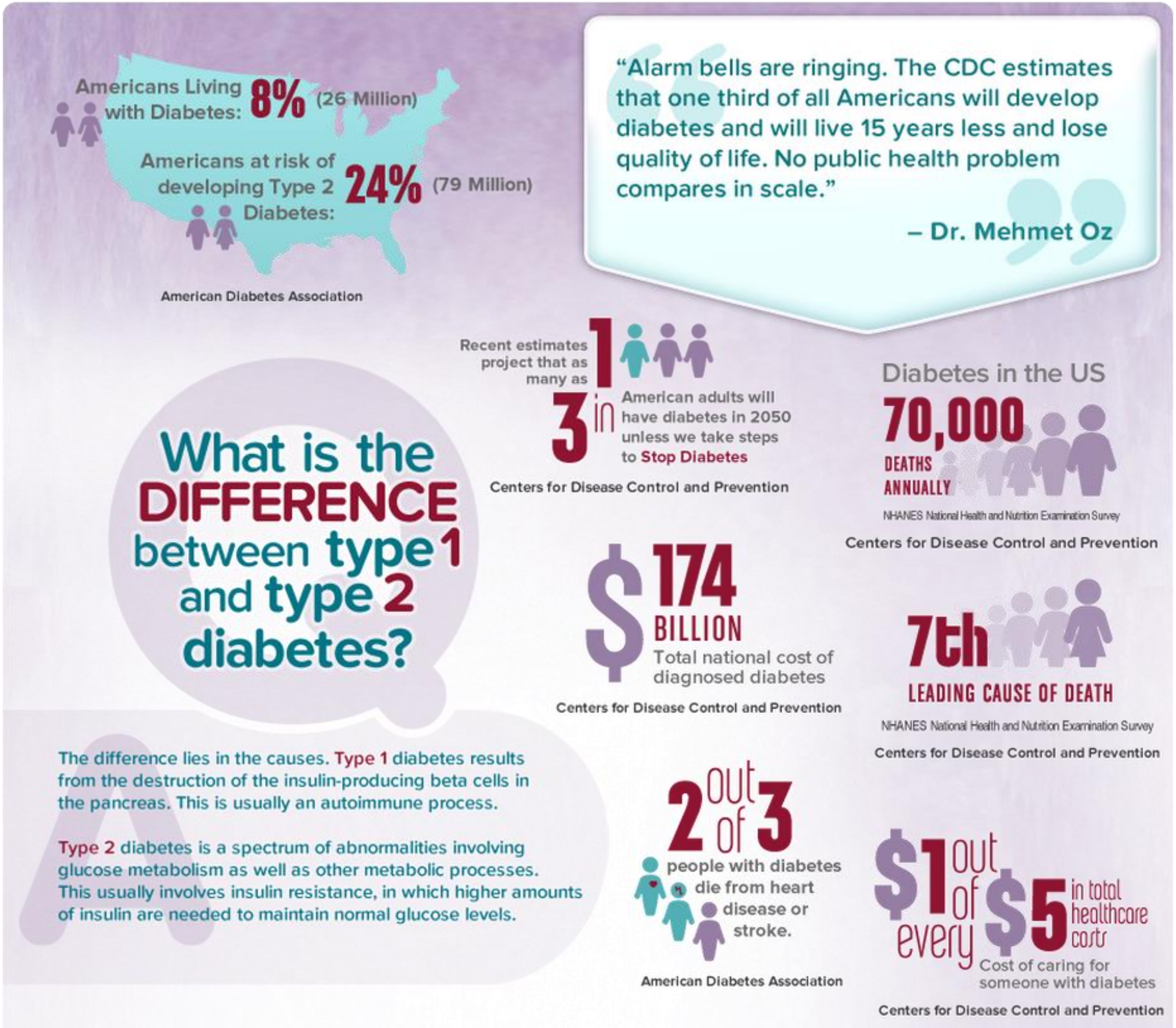
Relevance of anthocyanins on human health

Impact of Obesity

- More than one-third (36.5%) of U.S. adults have obesity with 49,190 estimated deaths in 2016.
- Obesity-related conditions include heart disease, stroke, type 2 diabetes and certain types of cancer, some of the leading causes of preventable death.
- The estimated annual medical cost of obesity in the U.S. was $147 billion in 2008 U.S. dollars; the medical costs for people who are obese were $1,429 higher than those of normal weight.

National Institutes of Health. (2017). Retrieved from http://seer.cancer.gov/statfacts/html/colorect.html

Diabetes



Americans Living with Diabetes: 8% (26 Million)
Americans at risk of developing Type 2 Diabetes: 24% (79 Million)
American Diabetes Association
"Alarm bells are ringing. The CDC estimates that one third of all Americans will develop diabetes and will live 15 years less and lose quality of life. No public health problem compares in scale."
– Dr. Mehmet Oz
Recent estimates project that as many as 1 in 3 American adults will have diabetes in 2050 unless we take steps to Stop Diabetes
Centers for Disease Control and Prevention
Diabetes in the US
70,000 DEATHS ANNUALLY
NHANES National Health and Nutrition Examination Survey
Centers for Disease Control and Prevention
What is the DIFFERENCE between type 1 and type 2 diabetes?
$174 BILLION
Total national cost of diagnosed diabetes
Centers for Disease Control and Prevention
7th LEADING CAUSE OF DEATH
NHANES National Health and Nutrition Examination Survey
Centers for Disease Control and Prevention
The difference lies in the causes. Type 1 diabetes results from the destruction of the insulin-producing beta cells in the pancreas. This is usually an autoimmune process.
Type 2 diabetes is a spectrum of abnormalities involving glucose metabolism as well as other metabolic processes. This usually involves insulin resistance, in which higher amounts of insulin are needed to maintain normal glucose levels.
2 out of 3 people with diabetes die from heart disease or stroke.
American Diabetes Association
$1 out of every $5 in total healthcare costs
Cost of caring for someone with diabetes
Centers for Disease Control and Prevention

Diabetes-improving properties of phenolic compounds such as anthocyanins in humans

- Improved insulin sensitivity
- Associated with a favorable glycemic response
- Reductions in fasting glucose and insulin levels
- Ameliorated post-prandial increase in plasma glucose
- Lowered insulin demand and index, and lowered glycemia
- Reduced risk for type-2 diabetes

Chen 2011; Wilson 2010; Udani 2011; Granfeldt 2011; Stull 2010; Wedick 2013.

A consensus about the recommended anthocyanin intake is needed

- Nowadays, it does not exist a recommended daily allowance for anthocyanins.

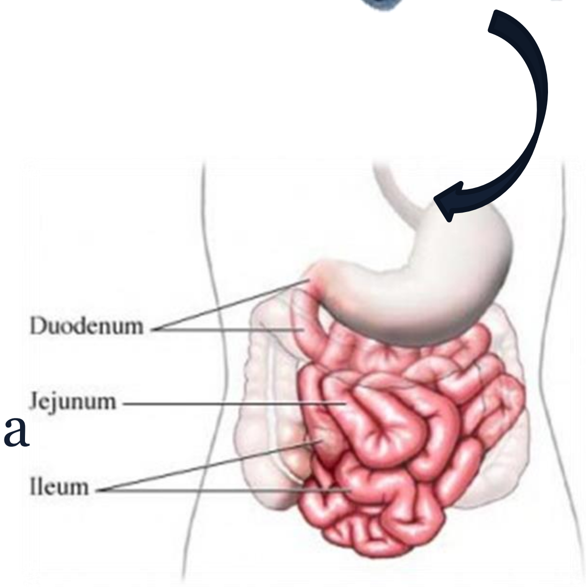
- Some authors suggest a consumption between **250–400 mg/d**.

- European Prospective Investigation into Cancer and Nutrition (EPIC) estimated a total anthocyanidin mean intake of **64·88 mg/d and 44·08 mg/d** for men and women, respectively (Turin, Italy).

Azzini *et al.*, 2017. Ox Med Cell Long, Article ID 2740364

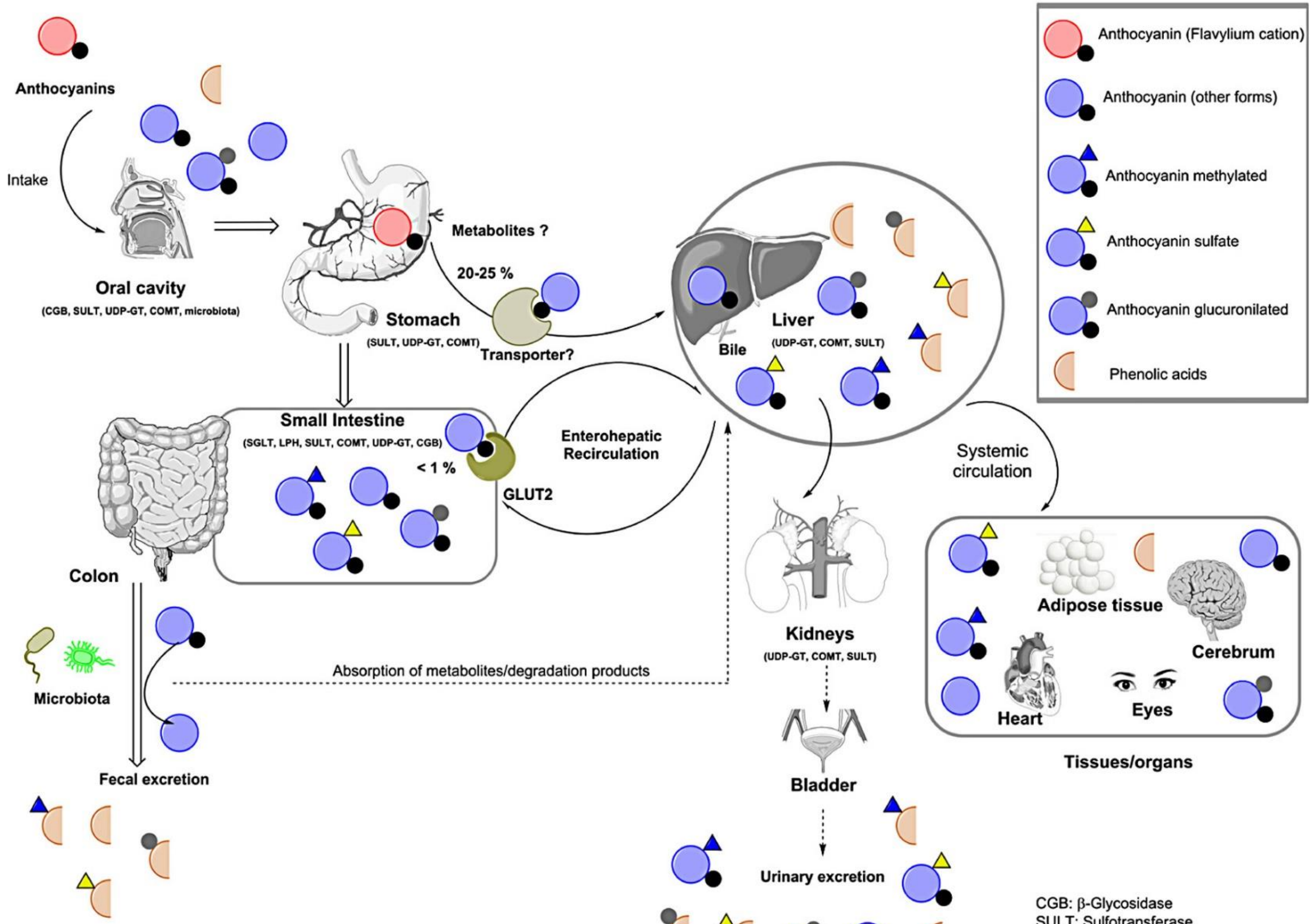
Absorption and Metabolism of Anthocyanins

- Consumption among the highest of all flavonoids due to their wide distribution in foods.
- Estimated daily intake of anthocyanins in the United States is between **180-215 mg**, may be as low as 12.5 mg per day.
  - Absorption mainly in the small intestine and stomach.
    - Very efficient epithelial tissue uptake.
    - Gut microbiota cleave glycosidic linkages.
    - Reach peak plasma concentrations quickly.
      - 1-120 nM
- Less than 1% recovery in urine.
- Metabolites and degradation products may play a key role in their biological activity.

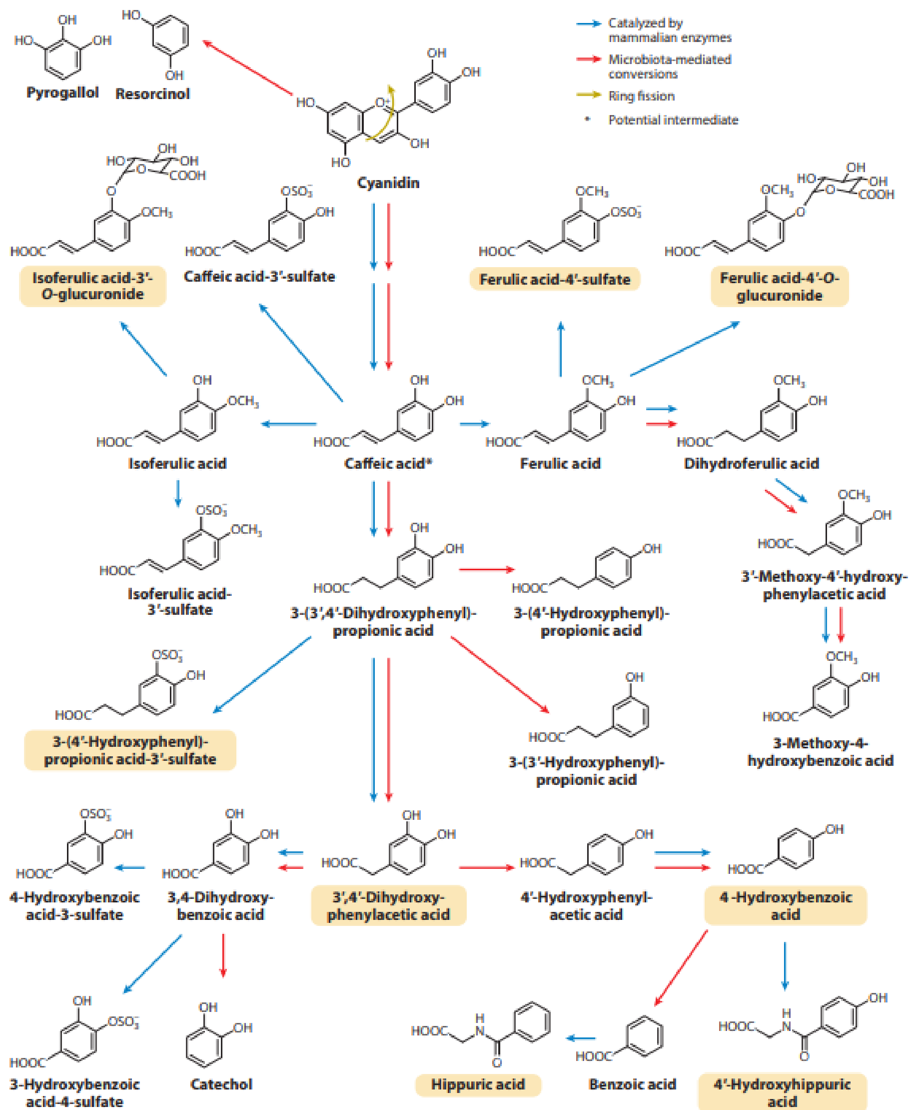


Faria 2009; Novotny 2012.

Anthocyanin absorption, distribution, metabolism and excretion based on current information



Anthocyanins are more bioavailable in humans than previously perceived

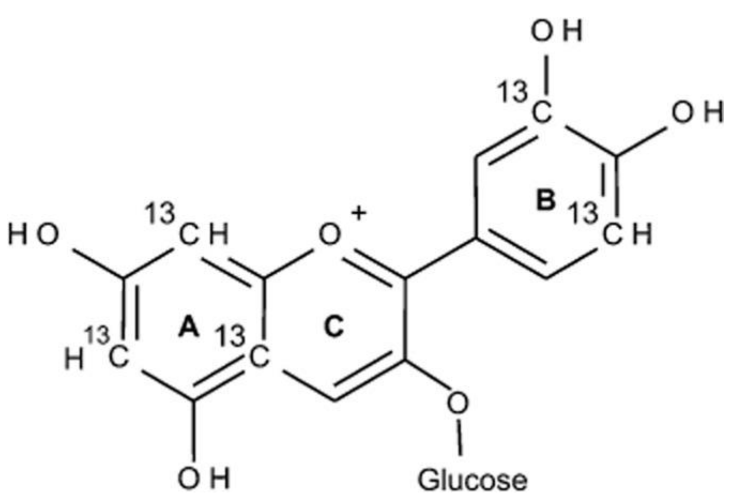


Kay *et al.*, 2017. Annu Rev Food Sci Technol, 8: 155-180

Pharmacokinetics of anthocyanins and their metabolites in humans

Experimental approach:

- 500 mg of C5-labeled cyanidin-3-glucoside
- 8 healthy male participants
- Collection of samples at 0, 0.5, 1, 2, 4, 6, 24 and 48 h
- Samples were analyzed by HPLC-ESI-MS/MS



Ferrars *et al.*, 2014. Brit J Pharmacol, 171 (13), 3268–3282

Pharmacokinetics of anthocyanins: key results

Seventeen 13C-labelled compounds were identified

- C3G
- Protocatechuic acid (PCA)
- Phloroglucinaldehyde (PGA)
- 13 metabolites of PCA
- 1 metabolite of PGA
- C_{max} of the metabolites ranged from 10 to 2000 nM between 2 and 30 h (t_{max})
- Half-lives of elimination between 0.5 and 96 h

Ferrars *et al.*, 2014. Brit J Pharmacol, 171 (13), 3268–3282

Concentration of C3G and degradants in plasma, urine and feces

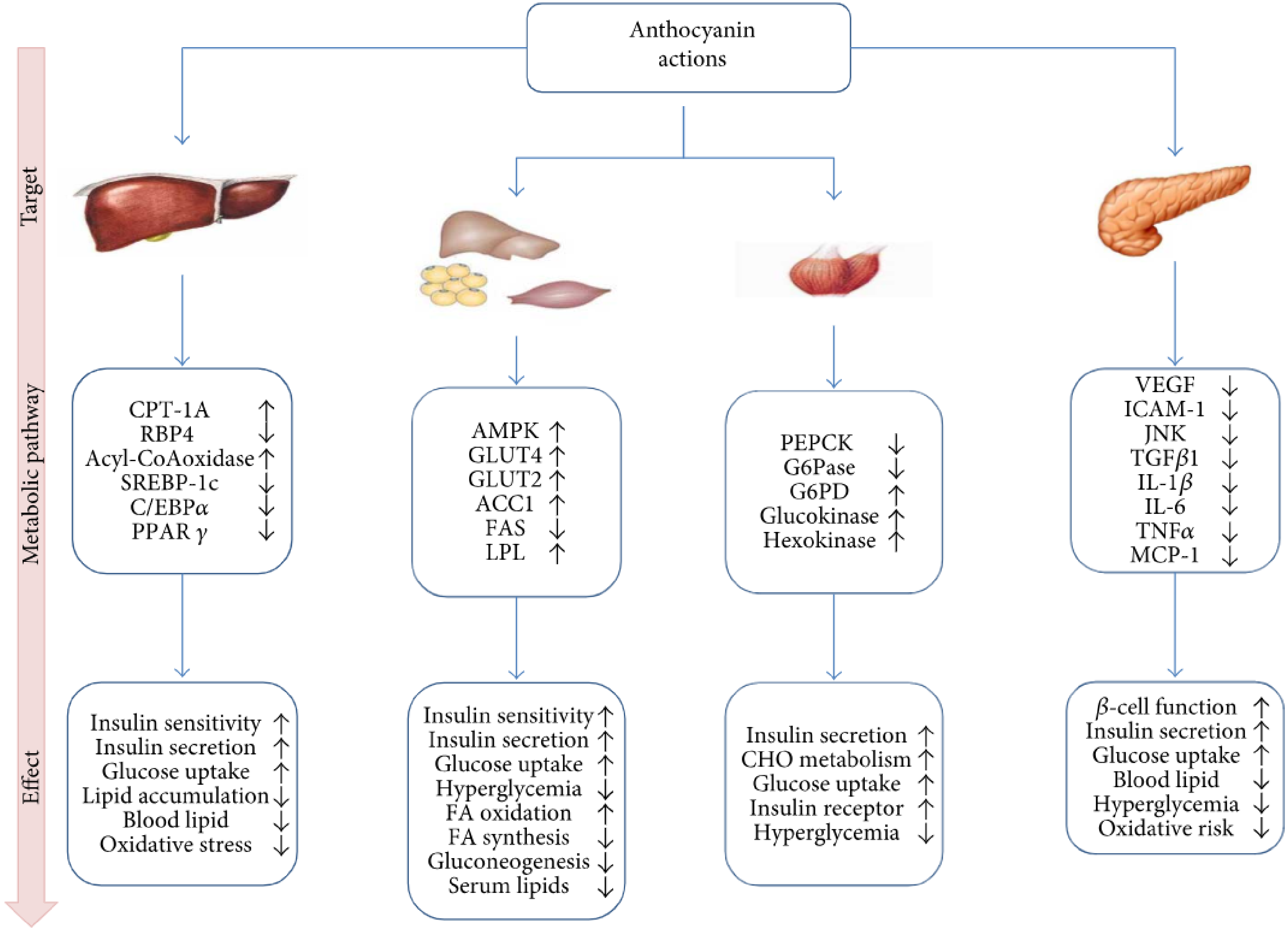
	C3G		PCA		PGA	
	C_{max} (nM)	t_{max} (h)	C_{max} (nM)	t_{max} (h)	C_{max} (nM)	t_{max} (h)
Plasma	141	1.8	146	3.3	**582**	2.8
Urine	**334**	1-2	**337**	1-2	170	6-24
Feces	70	6-24	**360**	6-24	113	24-48

C3G: Cyanidin-3-O-glucoside
PCA: Protocatechuic acid
PGA: Phloroglucinaldehyde
C_{max}: maximum concentration
t_{max}: time at maximum concentration

Ferrars *et al.*, 2014. Brit J Pharmacol, 171 (13), 3268–3282

Clinical evidence of the beneficial effects of anthocyanins from dietary sources in metabolic disorders

Beneficial effects of anthocyanins: general overview



Azzini *et al.*, 2017. Ox Med Cell Long, Article ID 2740364

Clinical studies retrieved from the http://ClinicalTrials.gov database on anthocyanins interventional studies and obesity

Conditions

- Overweight
- Type-2 diabetes
- Dyslipidemia
- Insulin resistant
- Childhood obesity

Number of studies: 10
Time frame: 2010 – 2017
Participants: 18 to 60
Total of participants: 366
Age: 18 to 65 y.o.

Sources

- Blackberry juice(250 mL)
- Blackberry extract (1.4 g)
- Freeze-dried strawberries (25-50 g)
- Blueberry powder (45 g)
- Fresh blackcurrants (80 g)
- Aronia juice (1000 mg/gallic acid eq/100 mL)

Primary outcomes

- Plasma concentrations of anthocyanins and metabolites
- Changes in lipids and lipoproteins
- Improvement in insulin sensitivity
- Reduction in glycosylated hemoglobin
- Reduction in blood cholesterol

Azzini *et al*., 2017. Ox Med Cell Long, Article ID 2740364

Anthocyanin Rich-Black Soybean Testa Improved Visceral Fat and Plasma Lipid Profiles in Overweight/Obese Adults: A Randomized double-blind placebo-controlled trial

- n=80 overweight participants
- 40 received black soybean extract, 40 received placebo
- Dose: 2.5 g/day anthocyanin-rich black soybean testa extracts with high concentrations of anthocyanins (12.58 mg/g)
- Eight weeks
- Age 19 and 65 years
- Body mass index (BMI) >23 (kg/m2)

Lee *et al.*, 2016. J Med Food, 19 (11), 995–1003

Significant decreases

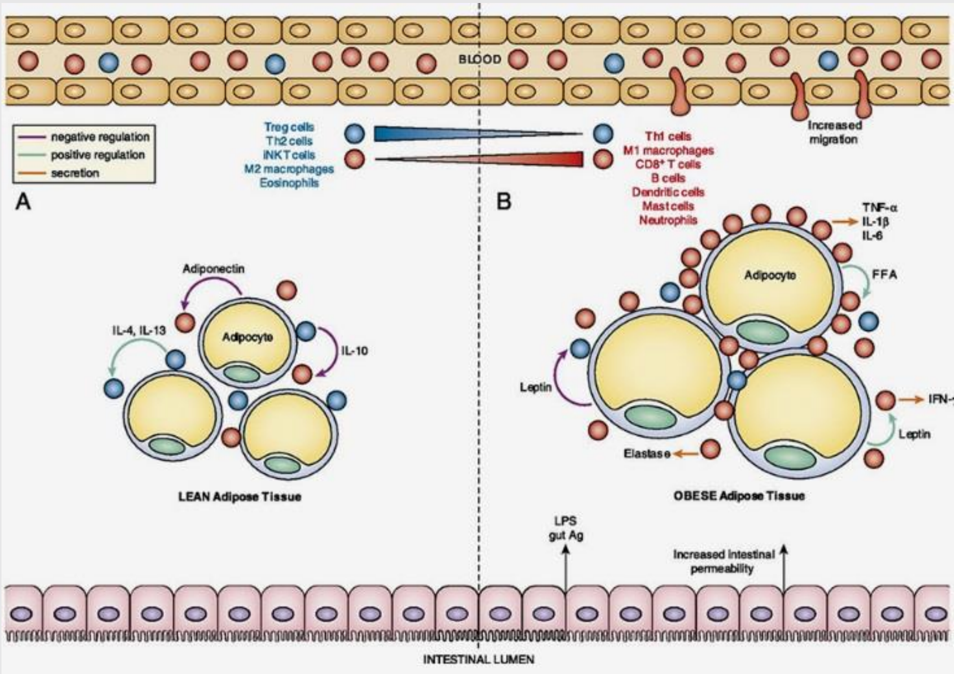
- waist circumference (approx. 2 cm),
- triacylglycerols (TG) (≈25%),
- low density lipoprotein cholesterol (LDLc) (≈20%),
- non-high density lipoprotein cholesterol (non-HDLc) (≈15%).

BBT can potentially be developed as a functional food for preventing abdominal obesity with high fiber and low cholesterol diets.

Lee *et al.*, 2016. J Med Food, 19 (11), 995–1003

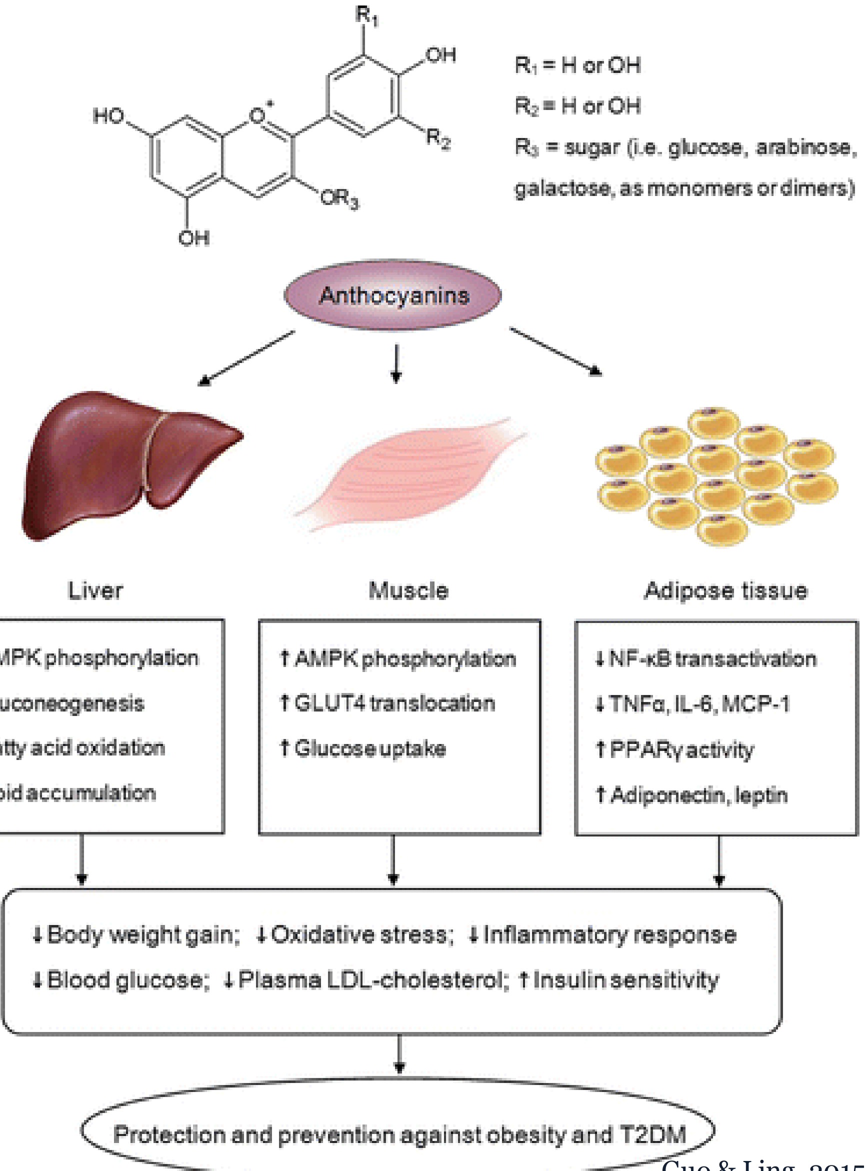
Effect of anthocyanins on obesity and type-2 diabetes

- Inhibition of body weight gain
- Relief of oxidative stress
- Regulation of inflammatory response
- Improvement of insulin resistance
- Alleviation of chronic diabetic complications



Guo and Ling. 2015. The update of anthocyanins on obesity and type 2 diabetes: Experimental evidence and clinical perspectives. Reviews in Endocrine and Metabolic Disorders, 16 (1):1–13

Overall effects of anthocyanins in obesity and type-2 diabetes



Guo & Ling, 2015. Rev Endocr Metab Disord, 16(1):1-13

Inhibition of body weight gain by anthocyanins

- Anthocyanins from black soybean efficiently prevented obesity in rats by inhibiting neuropeptide Y and activating the γ-amino butyric acid (GABA) receptor in the hypothalamus

+

Satiety	Metabolic activation
• ↑≈80% GABA-R • ↓≈50% Neuropeptide-Y • **Both markers measured in the hypothalamus**	• ↓16% Body weight gain • ↓ ≈20% daily average food intake

−

Adult male Sprague-Dawley rats
n= 6
24 mg anthocyanins/kg BW/day
40 days

- Translational studies using anthocyanins preventing body weight gain in humans is not conclusive yet.

Badshah *et al.*, 2013. Neuropeptides, 47(5): 347-353

Relief of oxidative stress by anthocyanins

- Obesity and prediabetes increase generation of reactive oxygen species (ROS).
- Anthocyanins may serve as free radical scavengers, however, emerging evidence suggest that they exert modulatory actions on antioxidant signaling molecules.

One-month strawberry-rich anthocyanin supplementation ameliorated oxidative stress markers in humans

n=23 healthy participants (men and women, 23 to 31 y.o.)
500 g fresh strawberries per day
30 days

Plasma

MDA ↓31%

Malondialdehyde
- Results from the lipid peroxidation of polyunsaturated fatty acids

Urine

Isoprostanes ↓27%

- Prostaglandin-like compounds
- Formed from the free radical-catalyzed peroxidation of fatty acids

Urine

8-OHdG ↓31%

8-Oxo-2'-deoxyguanosine
- Major product of DNA oxidation
- Marker of oxidative stress at cellular level

Alvarez-Suarez, 2014. J Nutr Biochem, 25(3):289-294
Guo & Ling, 2015. Rev Endocr Metab Disord, 16(1):1-13

Regulation of inflammatory response by anthocyanins

- Inflammation is a key component of obesity-related metabolic disorders such as type-2 diabetes.
- Several *in vitro* and *in vivo* studies have shown the anti-inflammatory effect of anthocyanins. However, the translation to human studies has not been completely achieved.

Açaí (*Euterpe oleracea* Mart.) beverage consumption improves biomarkers for inflammation but not glucose- or lipid-metabolism in individuals with metabolic syndrome

n=50 participants with metabolic syndrome
(men and women, 18 to 65 y.o.)
162.5 g of açaí pulp, per day
12 weeks

Plasma

IFN-γ ↓76%

Interferon-gamma
- Cytokine that is critical for innate and adaptive immunity.
- Is an important activator of macrophages

Urine

Isoprostanes ↓31%

- Prostaglandin-like compounds
- Formed from the free radical-catalyzed peroxidation of fatty acids

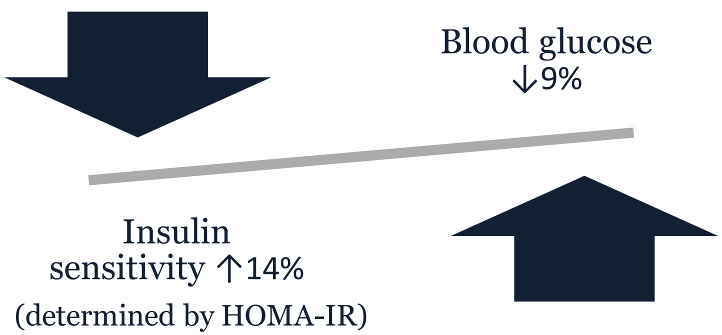
Kim *et al.*, 2018. Food Funct, 9:3097-3103
Qin & Anderson, 2012. Br J Nutr, 108(4):581-587

Improvement of insulin resistance by anthocyanins

- Obesity is strongly associated with insulin resistance, and the improvement of insulin resistance is important in preventing the development of type-2 diabetes.

Purified Anthocyanin Supplementation Reduces Dyslipidemia, Enhances Antioxidant Capacity, and Prevents Insulin Resistance in Diabetic Patients

n=58 participants with type-2 diabetes
(men and women, 56 - 67 y.o.)
320 mg anthocyanins per day (extracted from blueblerries)
24 weeks



Insulin levels in blood were not different from the baseline, which suggests that the anthocyanins promoted insulin sensitivity

Luna-Vital *et al.*, 2017. Mol Nutr Food Res., 61(12):1700362
Li *et al.*, 2015. J Nutr., 145(4):742-748

Clinical evidence of the beneficial effects of anthocyanins from dietary sources on markers of cardiovascular risk

Supplementation of Anthocyanins and Markers of Cardiovascular Disease

- 12 studies from 2005 to 2016
- n= 27 to 146 each
- Total of participants: 1,042
- Age: > 18 years
- Materials: elderberry extract (500 mg/day), whortleberry extract (1050 mg/day), chokeberry extract (255 mg/day), hibiscus (100 mg/day), purified anthocyanins

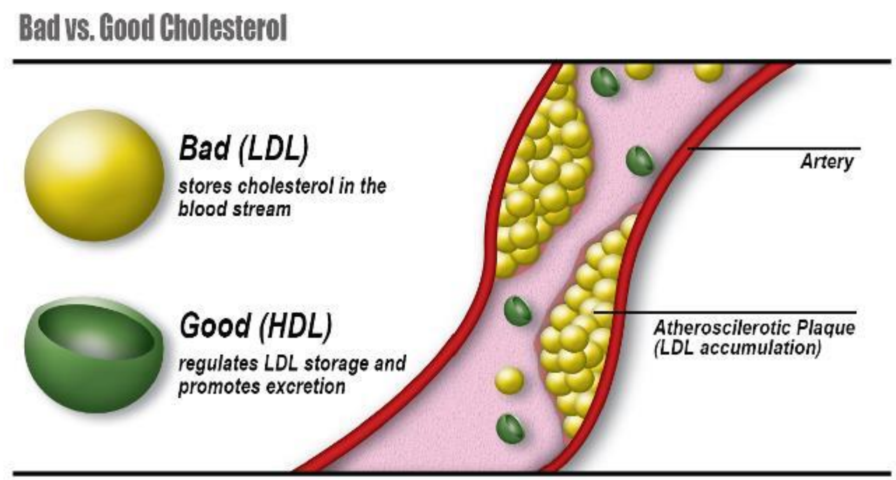
Wallace *et al.*, 2016. Nutrients, 8: 32

Effect of anthocyanins in cardiovascular disease markers: lipoproteins

ANC administration

7 to 500 mg/day

- Healthy subjects
  - Slight reduction in total cholesterol (up to -4.5%), no differences in LDL or HDL
- Dyslipidemic subjects
  - Reduction in LDL (up to -32%) and cholesterol (up to -28.9%), increase in HDL (up to 36%)



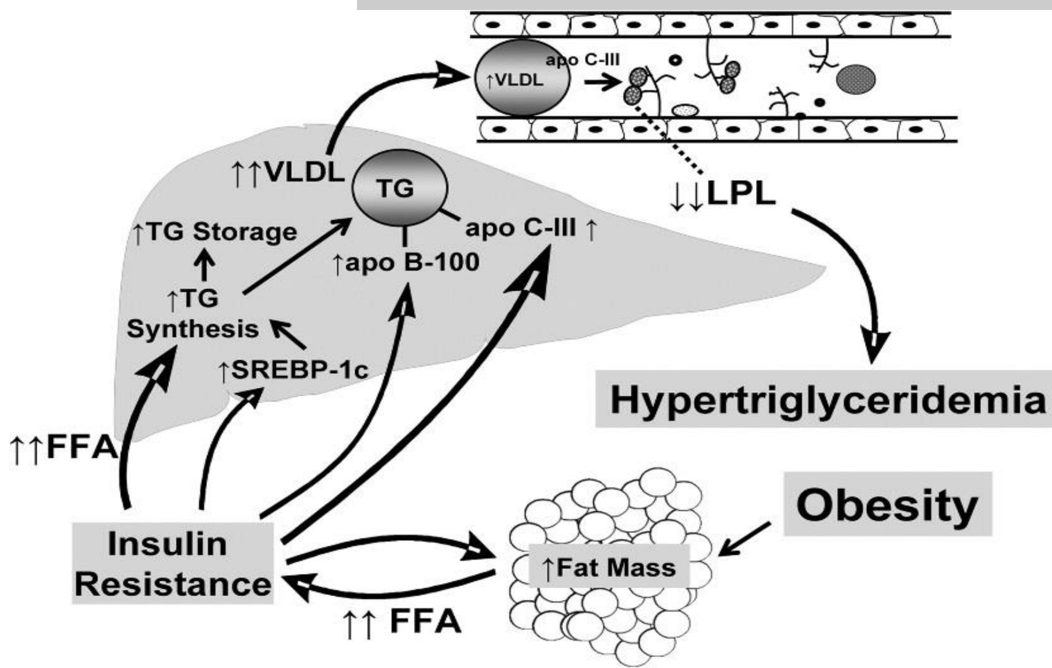
Wallace *et al.*, 2016. Nutrients, 8: 32

Effect of anthocyanins in cardiovascular disease markers: triglycerides

Healthy and dyslipidemic subjects

Up to 500 mg/day

Overall reduction of triglycerides (up to -37.9%)



Wallace *et al.*, 2016. Nutrients, 8: 32

Effect of anthocyanins in cardiovascular disease markers: blood pressure

Anthocyanin dose — Up to 500 mg/day

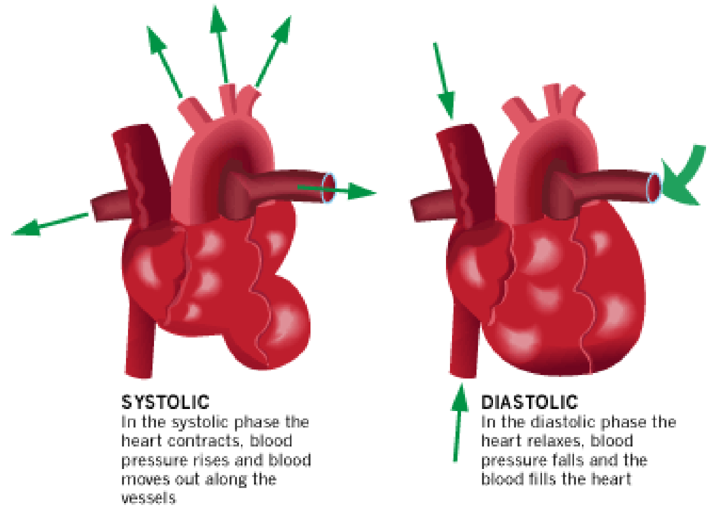
- 19.2 to 500 mg/day

Condition of the participants — Different types of health status

- Healthy, metabolic syndrome, post-myocardial infarction, prehypertension

Main outcomes — Changes in blood pressure

- Overall decrease of systolic (up to -8.3%) and diastolic (up to -13.5%) blood pressure



Wallace *et al*., 2016. Nutrients, 8: 32

Examples of clinical interventions and studies in humans to evaluate the beneficial effects of anthocyanins in cardiovascular disease markers

Improved Lipid Profile in Hyperlipidemic Patients Taking *Vaccinium arctostaphylos* Fruit Hydroalcoholic Extract: A Randomized Double-Blind Placebo-Controlled Clinical Trial

- n= 51 with whortleberry, 54 placebo
- Newly diagnosed primary hyperlipidemia
- Dose: 350 mg every 8 h (1.05 g of dry whortleberry daily) for 2 months

Kianbakht *et al*., 2013. Phytoter Res, 28(3):432–436

Whortleberry (*Vaccinium arctostaphylos*) reduced total cholesterol, triglyceride and LDL, and increased HDL compared with baseline

	Whortleberry group	Placebo group
Total cholesterol	↓28%	=
Triglycerides	↓19%	=
LDL	↓26%	=
HDL	↑37%	=

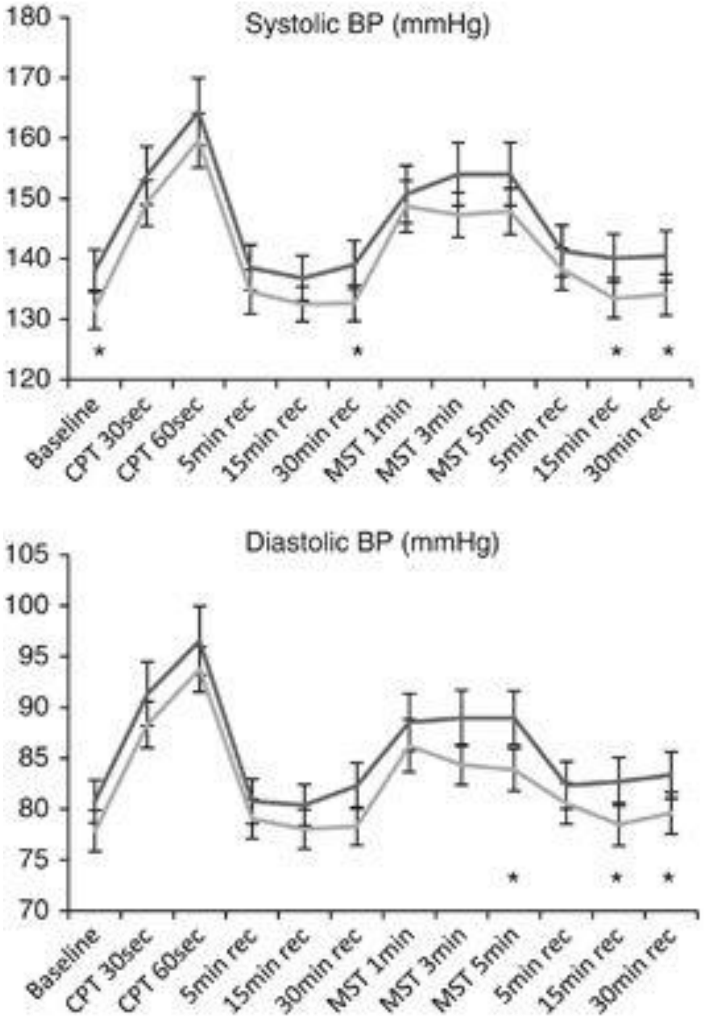
Kianbakht *et al.*, 2013. Phytoter Res, 28(3):432–436

Effect of anthocyanins on blood pressure and stress reactivity: a double-blind randomized placebo-controlled crossover study

- n=31 healthy men not on antihypertensive medication
- Dose: 320 mg anthocyanin twice daily (640 mg anthocyanin /day)
- Duration: 4 weeks
- Source: bilberries and blackcurrants

Hassellund *et al.*, 2012. J Hum Hypertens, 26: 396-404

Cardiovascular responses to anthocyanins comparing absolute differences across treatment periods

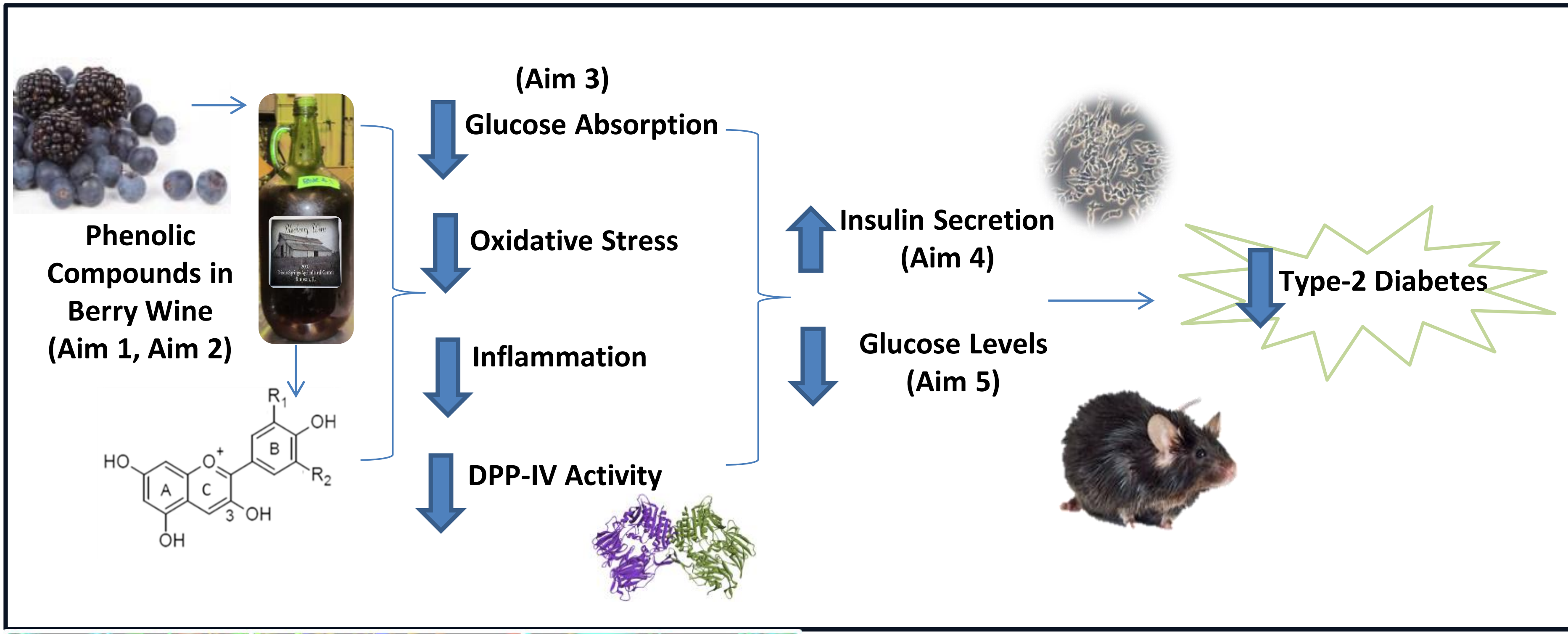


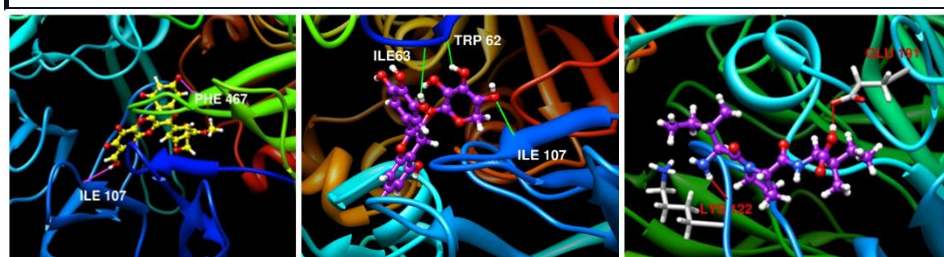
Systolic and diastolic blood pressure was reduced at different times of the study. However, the results are not conclusive, the most appropriate populations, doses, food mixtures and even anthocyanin molecules to maximize health benefits are yet to be found.

Hassellund *et al.*, 2012. J Hum Hypertens, 26: 396-404

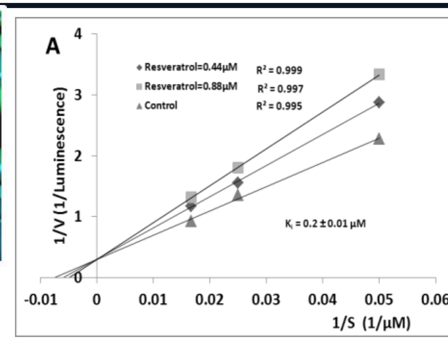
Anthocyanins: preclinical studies *in vitro* and *in vivo*

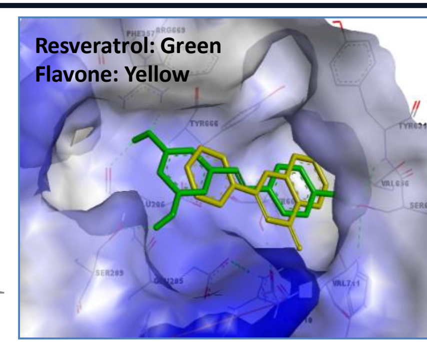
Comprehensive *in vitro* and *in vivo* evaluation of anthocyanins and proanthocyanidins from blueberry and blackberry fermented beverages on type-2 diabetes





Diprotin A -3208.3 kcal/mol | Delphinidin-3-arabinoside -3227.7 kcal/mol | Malvidin-3-galactoside -3106.9 kcal/mol

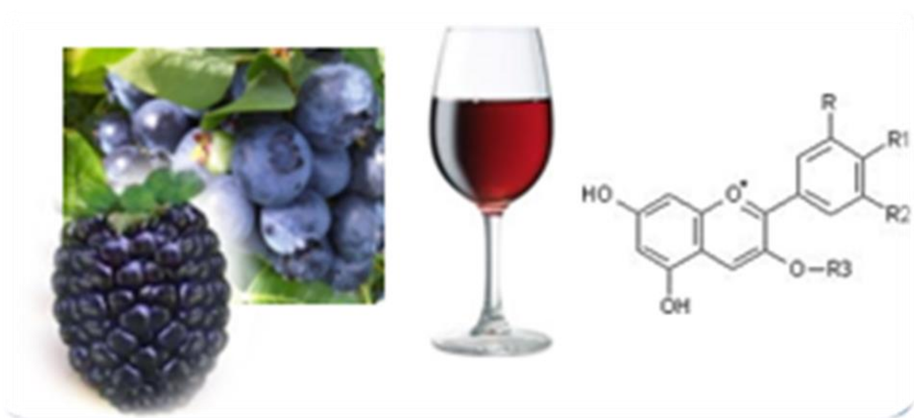




Anthocyanins and proanthocyanidins from blueberry and blackberry alcohol-free fermented beverages

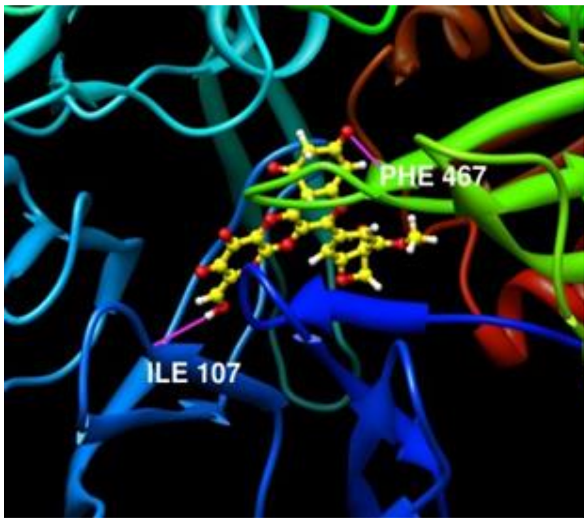
- Beneficial sources of antioxidants
- Inhibitors of carbohydrate-utilizing enzymes
- Potential inhibitors of inflammation

- There is potential for alcohol-free fermented berry beverages to reduce complications associated with chronic inflammatory diseases like type 2 diabetes.

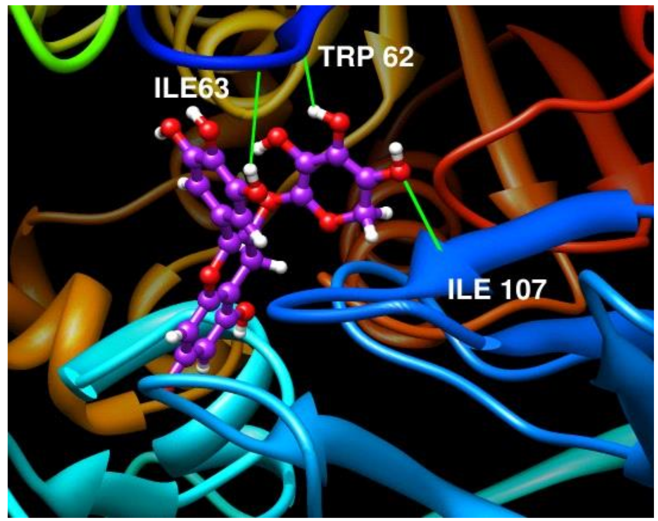


Computational model confirmed binding to DPP-IV:

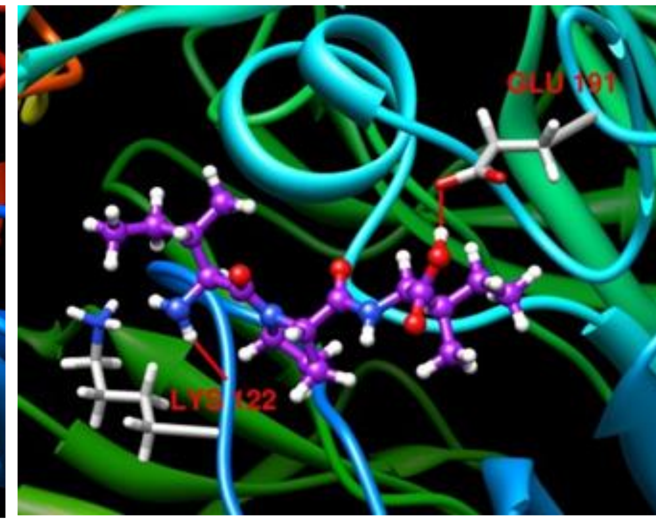
Delphinidin-3-arabinoside and malvidin-3-galactoside have similarly low interaction energies as diprotin A with DPP-IV enzyme.



Diprotin A
-3208.3 kcal/mol



Delphinidin-3-arabinoside
-3227.7 kcal/mol

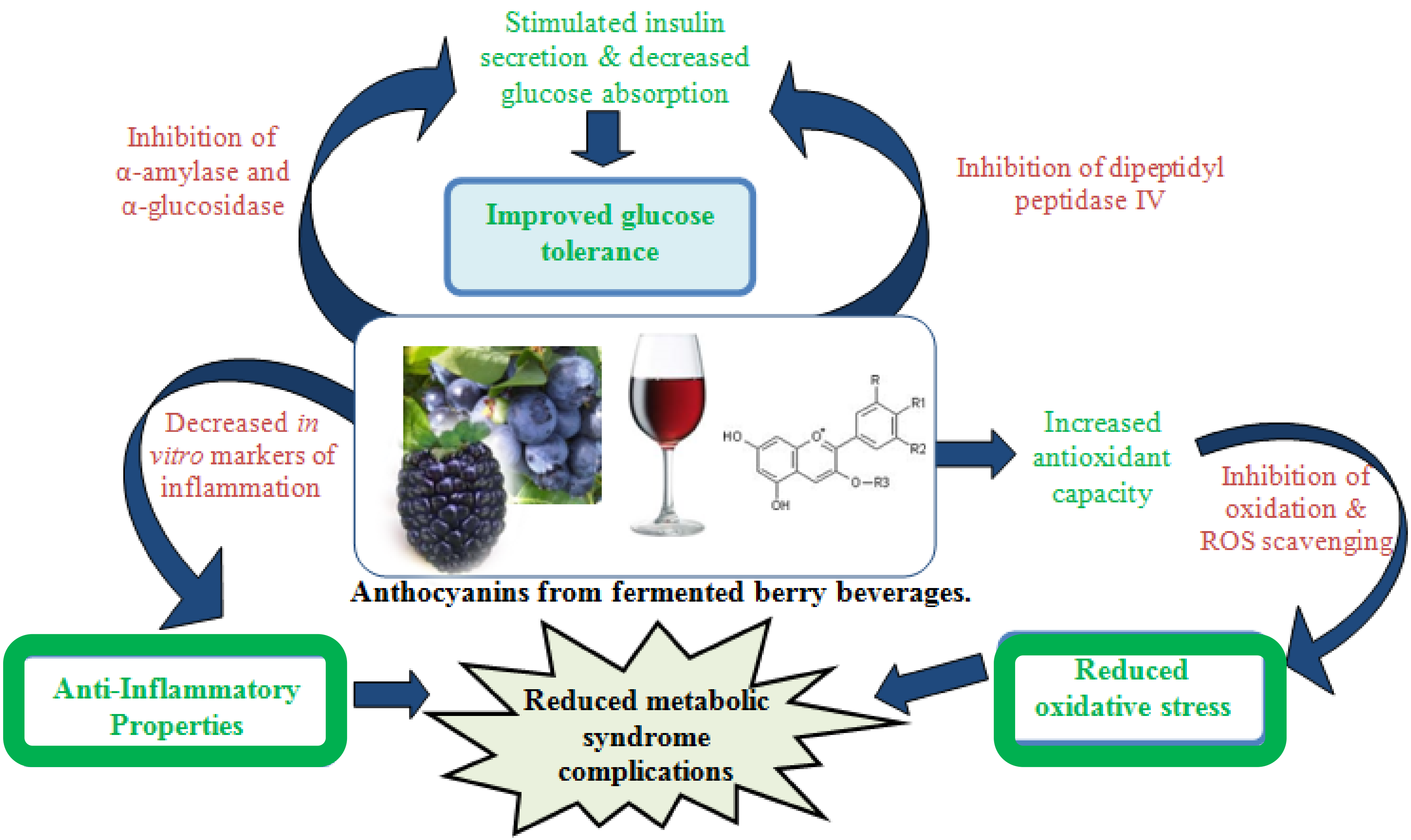


Malvidin-3-galactoside
-3106.9 kcal/mol

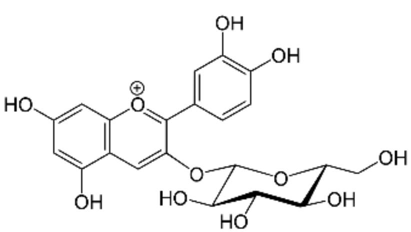
- The lower the interaction energy, the better the binding.

Johnson *et al.*, 2013. Mol Nutr Food Res. *57*(7), 1182-1197

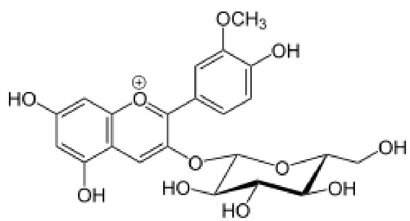
Role of anthocyanins from fermented berry beverages



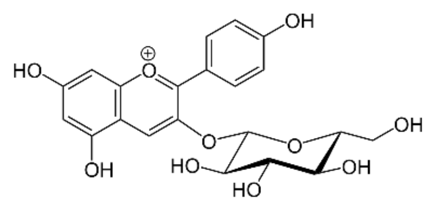
Colored corn as a source of natural pigments



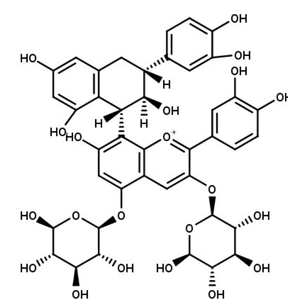
Peonidin-3-*O*-glucoside (P3G)



Pelargonidin-3-*O*-glucoside (Pr3G)

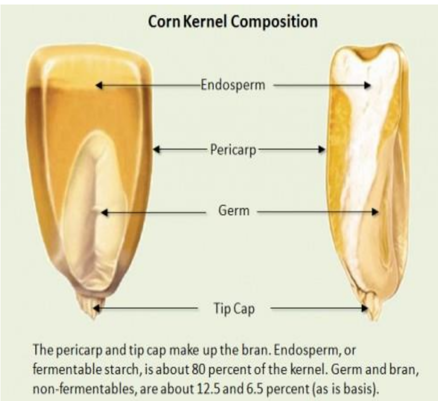


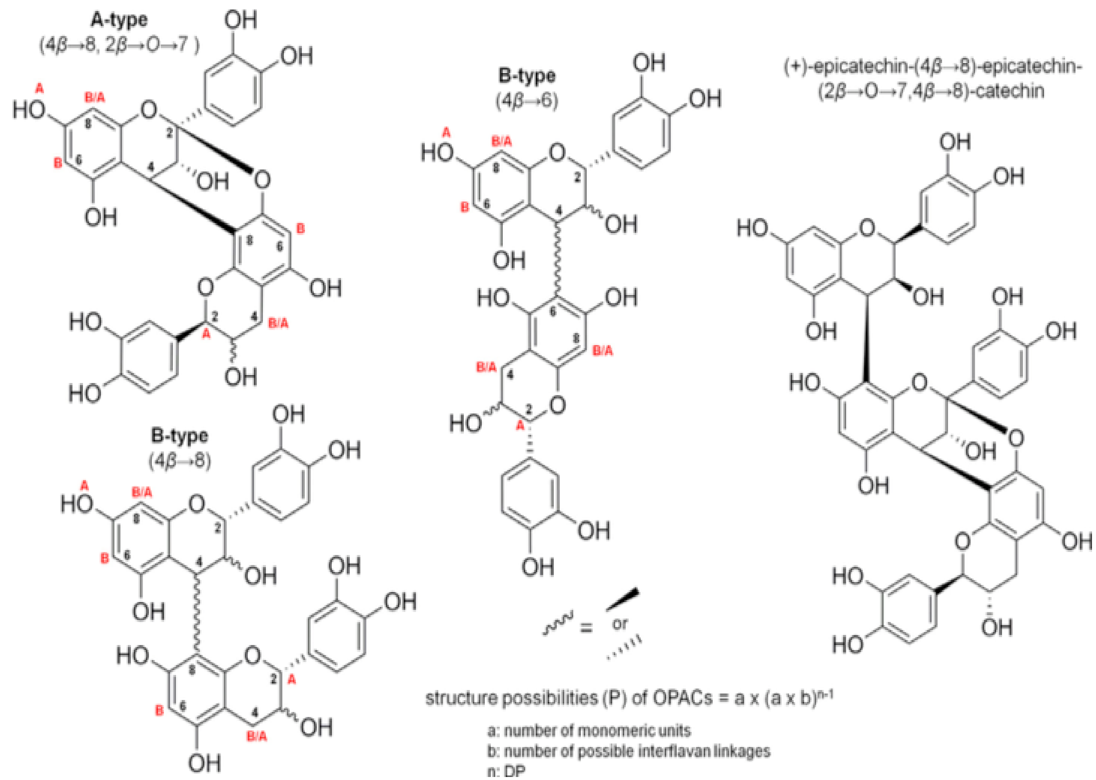
Cyanidin-3-*O*-glucoside (C3G)



Condensed forms (CF)

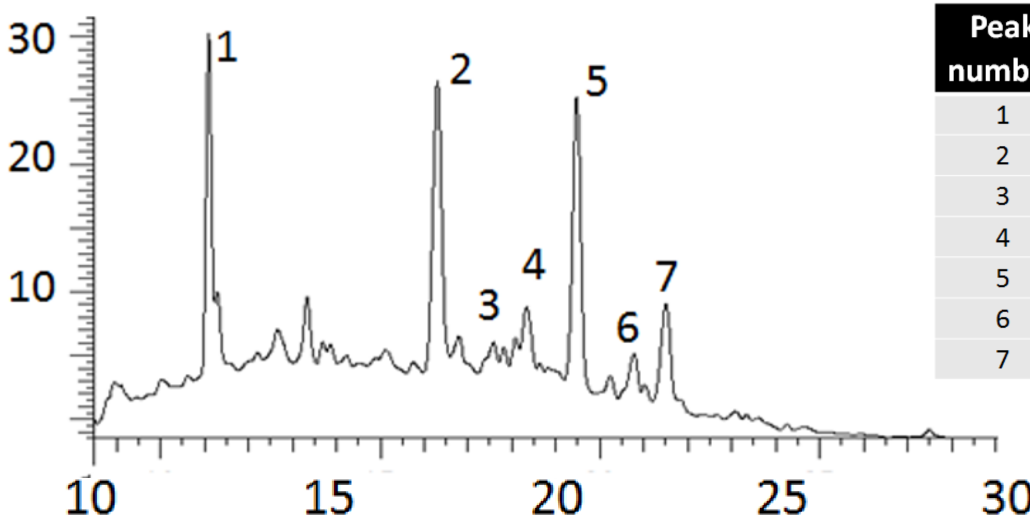
Proanthocyanidins from colored corn coproducts and the anti-inflammatory effect from purple and red corn pericarp



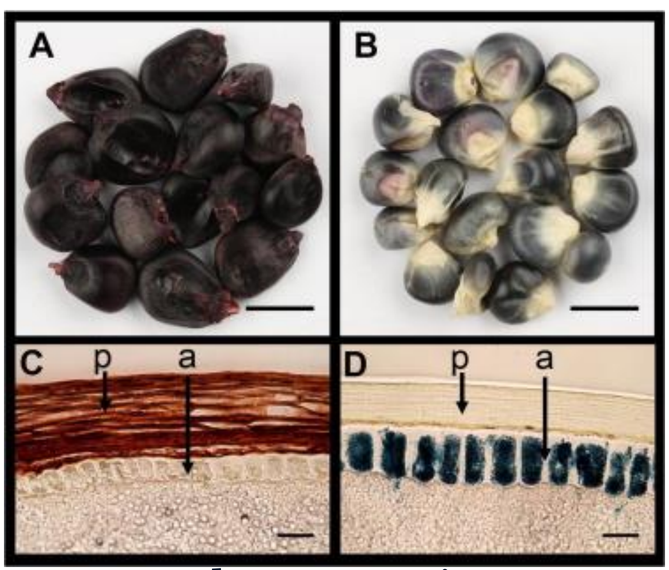


Chen, C., Somavat, P., Singh, V., Gonzalez **de Mejia**, E. 2017. Chemical characterization of proanthocyanidins in purple, blue, and red corn coproducts from different milling processes and their anti-inflammatory properties. *Ind Crops Prod*. 109C, 464-475.

Anthocyanins are present mainly in the pericarp and aleurone of colored corn



Peak number	Retention time (min)	Identity
1	11.0	Condensed forms
2	16.1	Cyanidin-3-glucoside
3	17.4	Pelargonidin-3-glucoside
4	18.1	Peonidin-3-glucoside
5	19.2	Cyanidin-3-O-(6”-malonyl-glucoside)
6	20.6	Pelargonidin-3-O-(6”-malonyl-glucoside)
7	21.3	Peonidin--3-O-(6”-malonyl-glucoside)

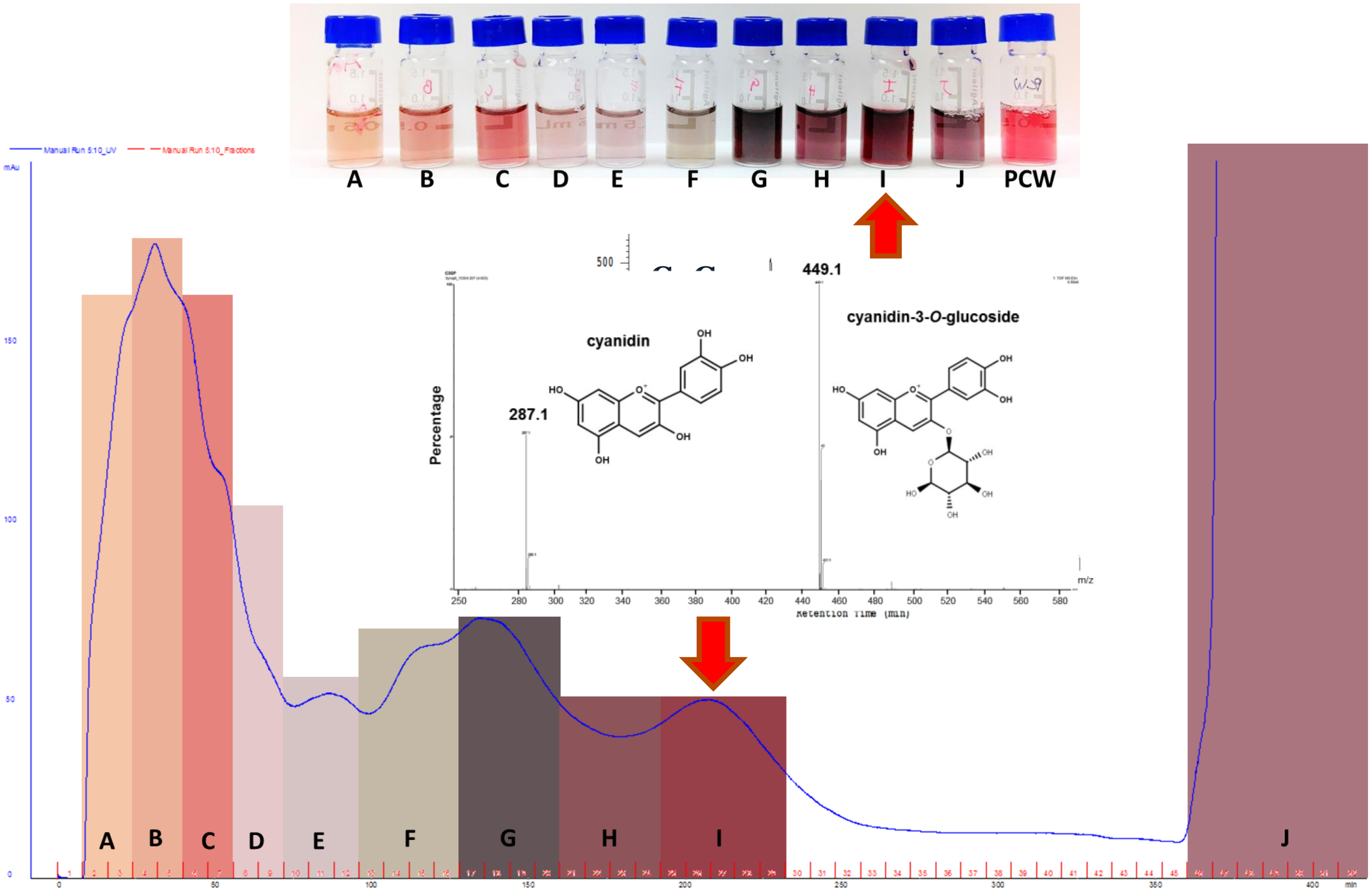


Purple corn pericarp

Anthocyanins are found in different sections depending on the variety.

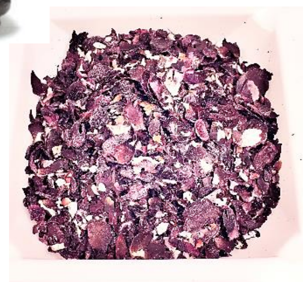
Li, Q., Somavat, P., Singh, V., Chatham, L., Gonzalez **de Mejia**, E. 2017. A comparative study of anthocyanin distribution in purple and blue corn coproducts from three conventional fractionation processes. Food Chem. 231, 332–339.

Fractionation and isolation of compounds from extracts of colored corn



Luna-Vital & de Mejia, 2018. PloS one. 13(7), e0200449

Using pressure-assisted extraction, it is possible to obtain food-grade pigments from colored corn

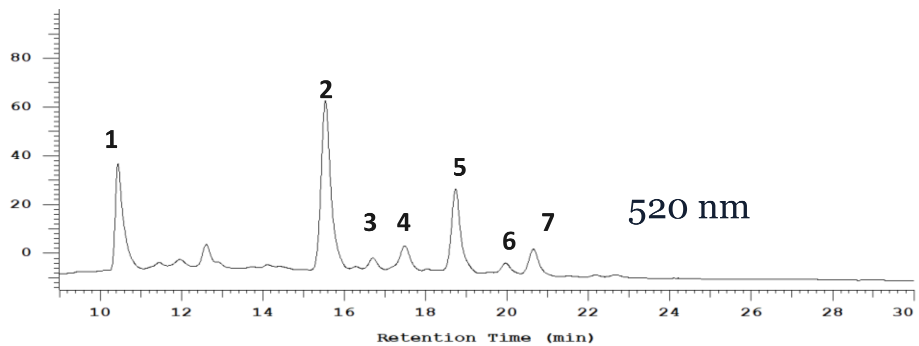


Colored maize pericarp

Pressure-assisted water extraction

Purple corn ANC-rich extract (PCW)

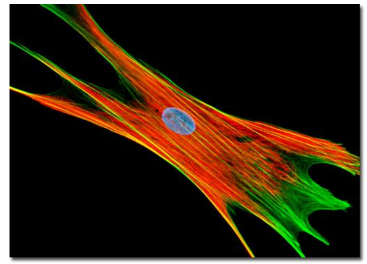
Peak	Name
1	CF
2	C3G
3	Pg3G
4	P3G
5	C3G-Mal
6	Pg3G-Mal
7	P3G-Mal



Anthocyanin identification by HPLC-MS-MS

Luna-Vital *et al.*, 2017. Food Chem. 232, 639-647

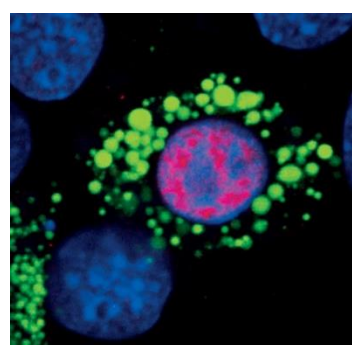
Methodology differentiation



3T3-L1 pre-adipocyte cells

Purple corn pericarp water extract

Hormone-driven differentiation
(IBMX, rosiglitazone, dexamethazone, insulin)
15 days

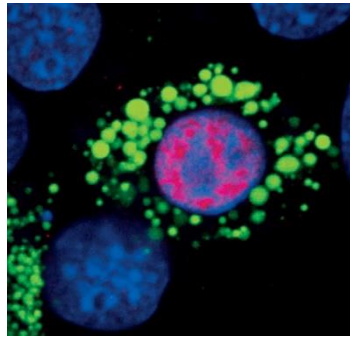


Fully-dfferentiated adipocytes

Differentiation parameters:
Lipid staining (Oil Red O)
PPAR-γ levels

Antiobesity parameters:
Lipase and FAS activity
Lipolysis
Molecular docking

Methodology inflammation



Fully-dfferentiated adipocytes

Purple corn pericarp water extract

8 days

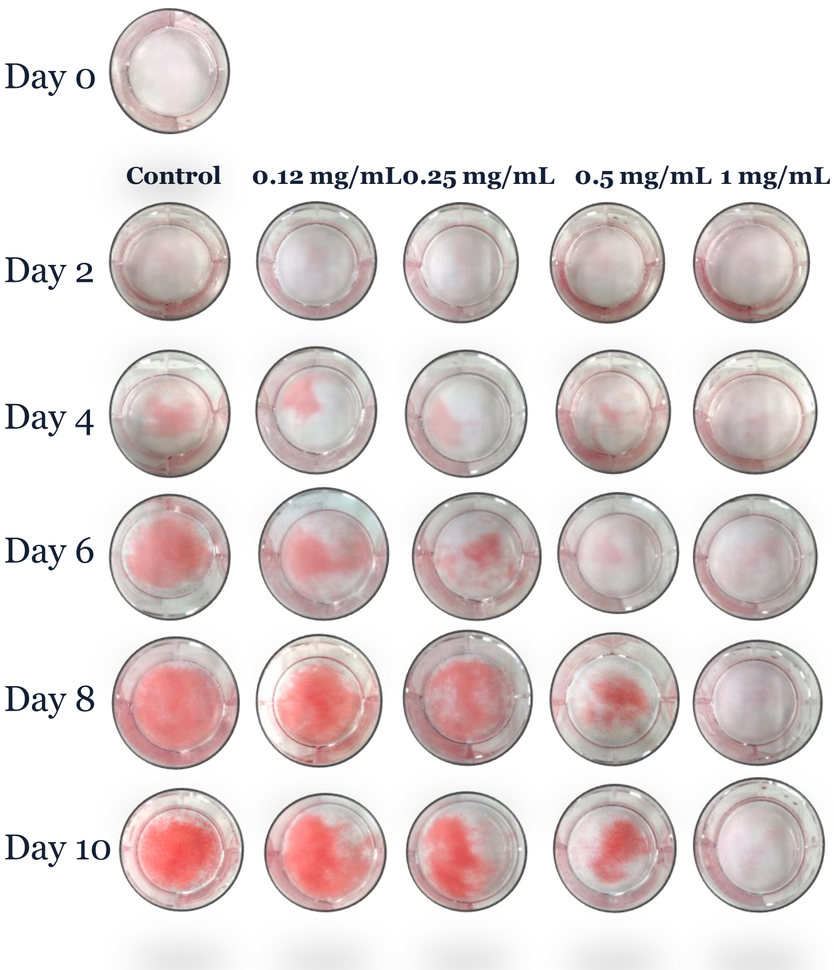
Tumor Necrosis Factor-α

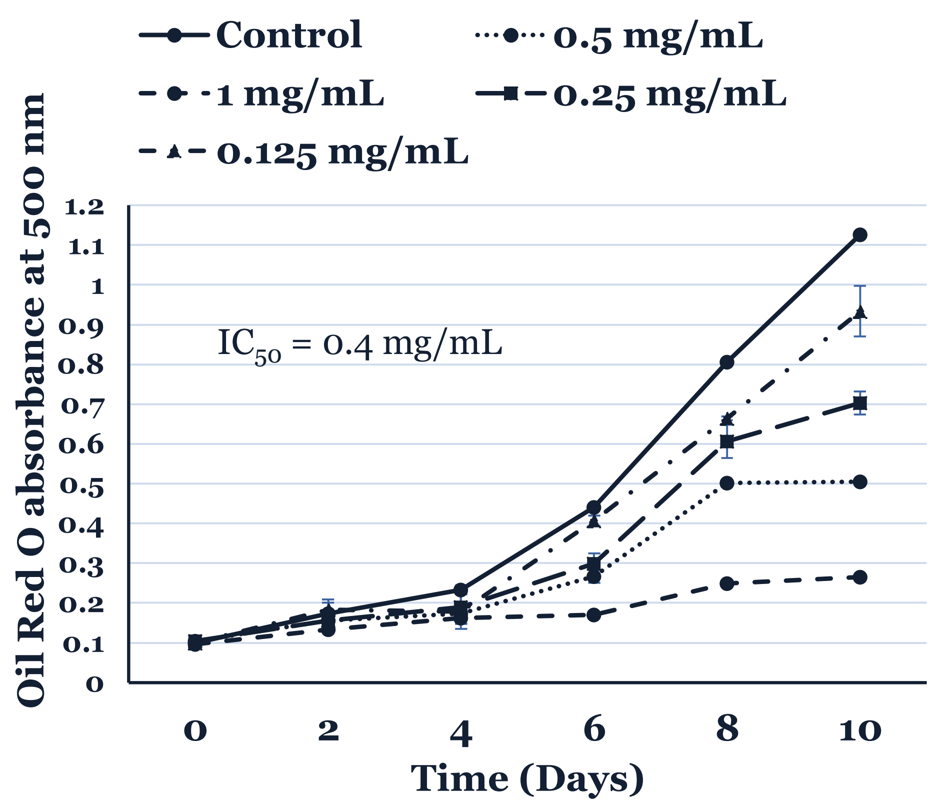
cell signaling protein involved in systemic inflammation

Inflammation
Insulin resistance

Immunodetection of adipokines and glucose uptake

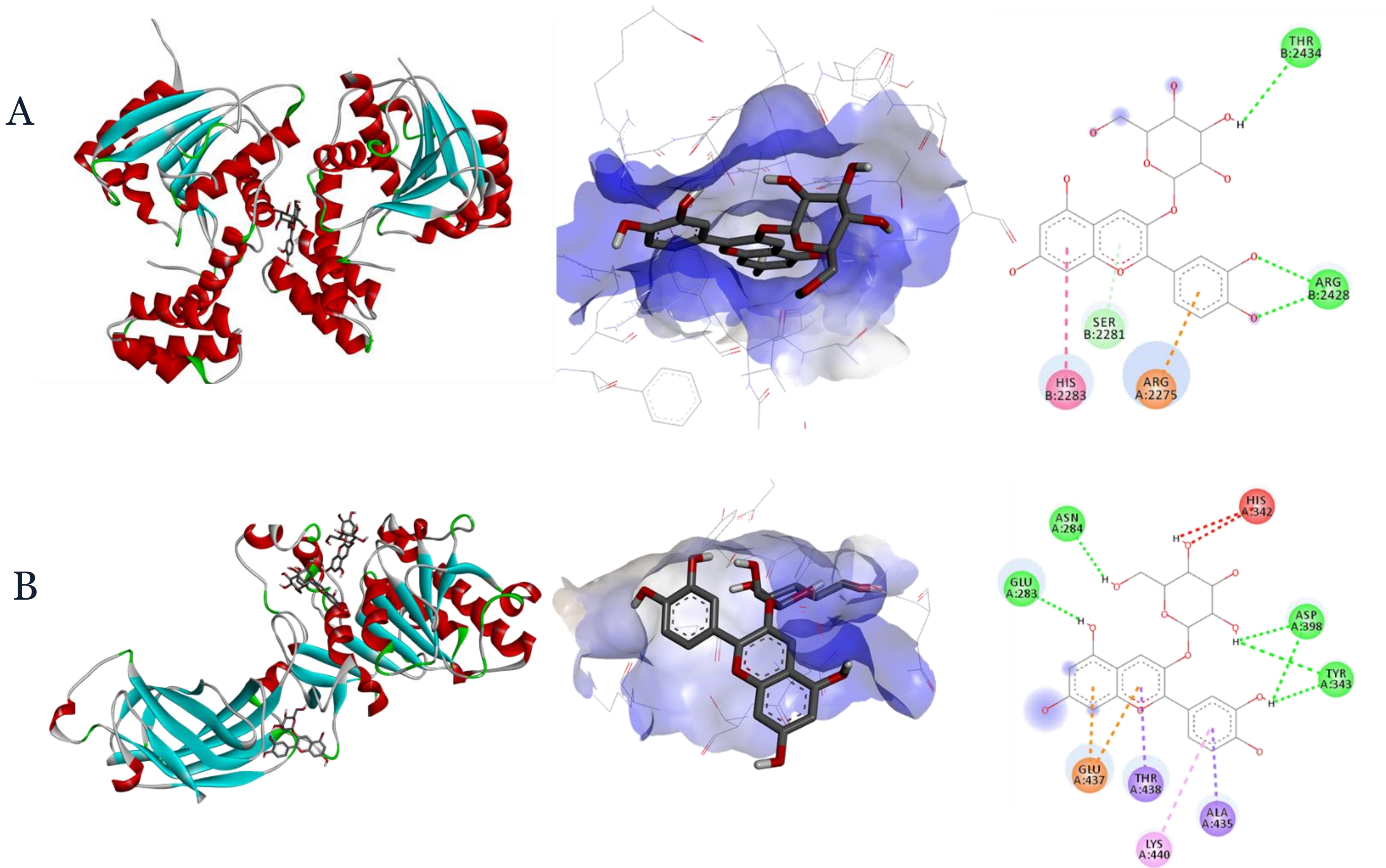
Anthocyanins from PCW inhibited adipocytes differentiation in a dose-response manner





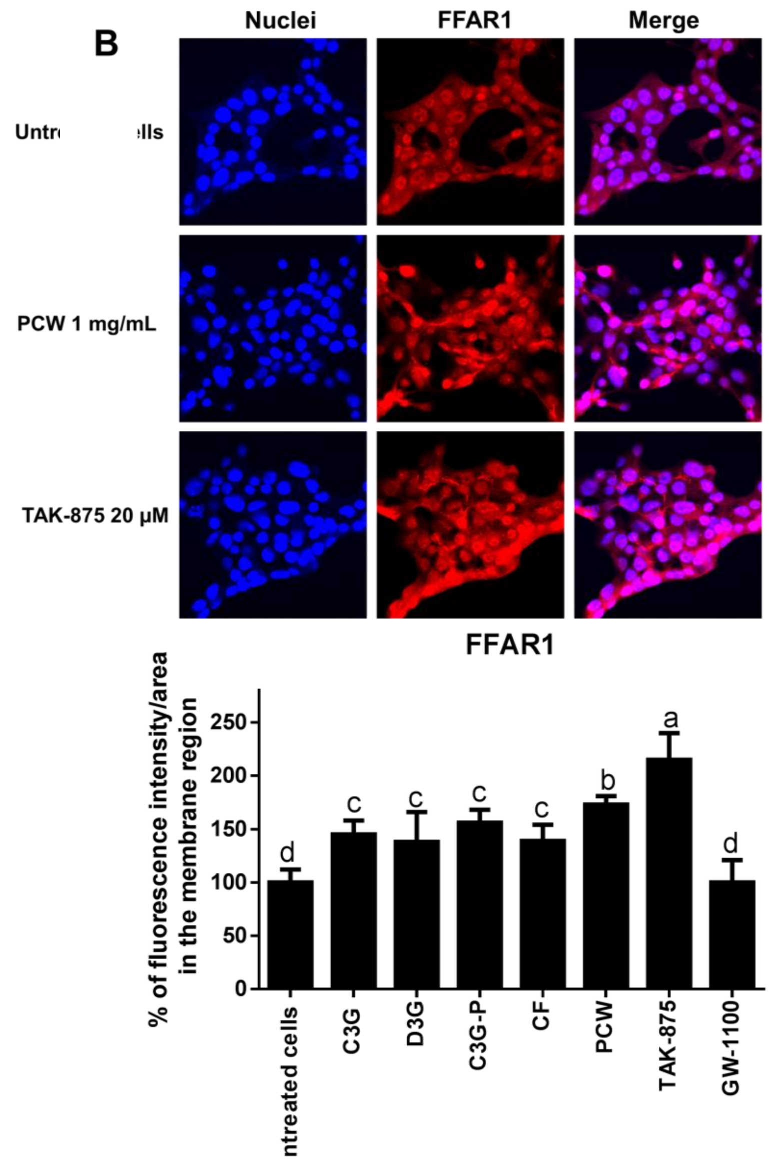
Luna-Vital *et al.*, 2017. *Mol. Nutr. Food Res.* 61(12), 1700362

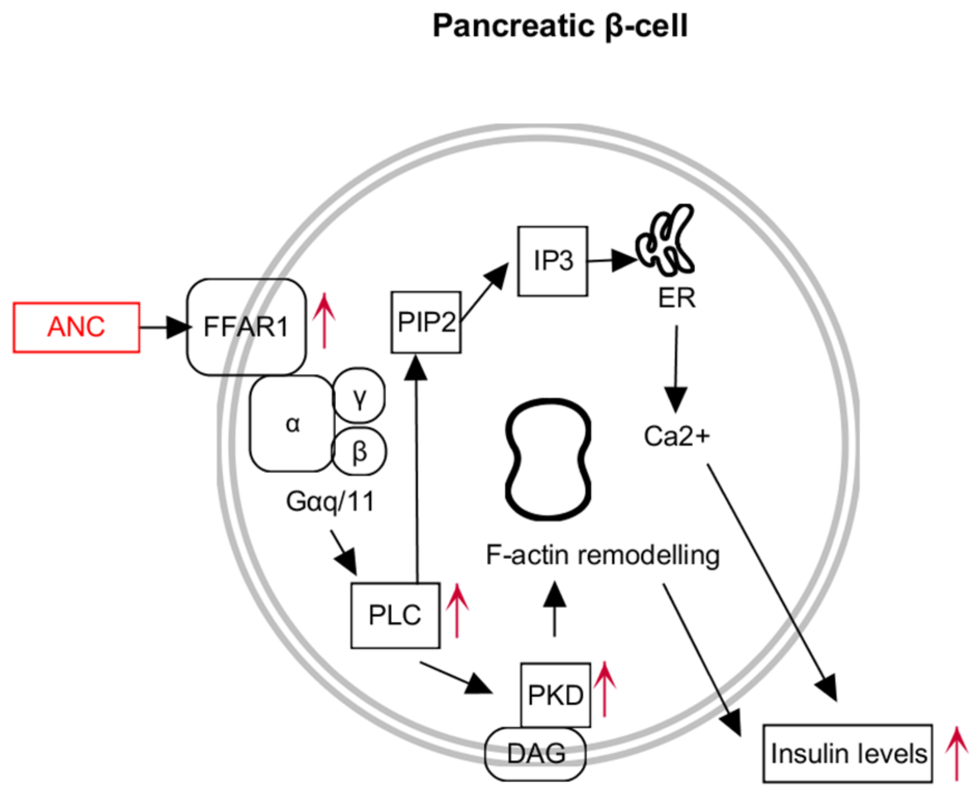
Interactions of cyanidin-3-*O*-glucoside with **A**) thioesterase domain of fatty acid synthase and **B**) the three identified pockets of lipoprotein lipase as determined by molecular docking



Luna-Vital *et al.*, 2017. *Mol. Nutr. Food Res.* 61(12), 1700362

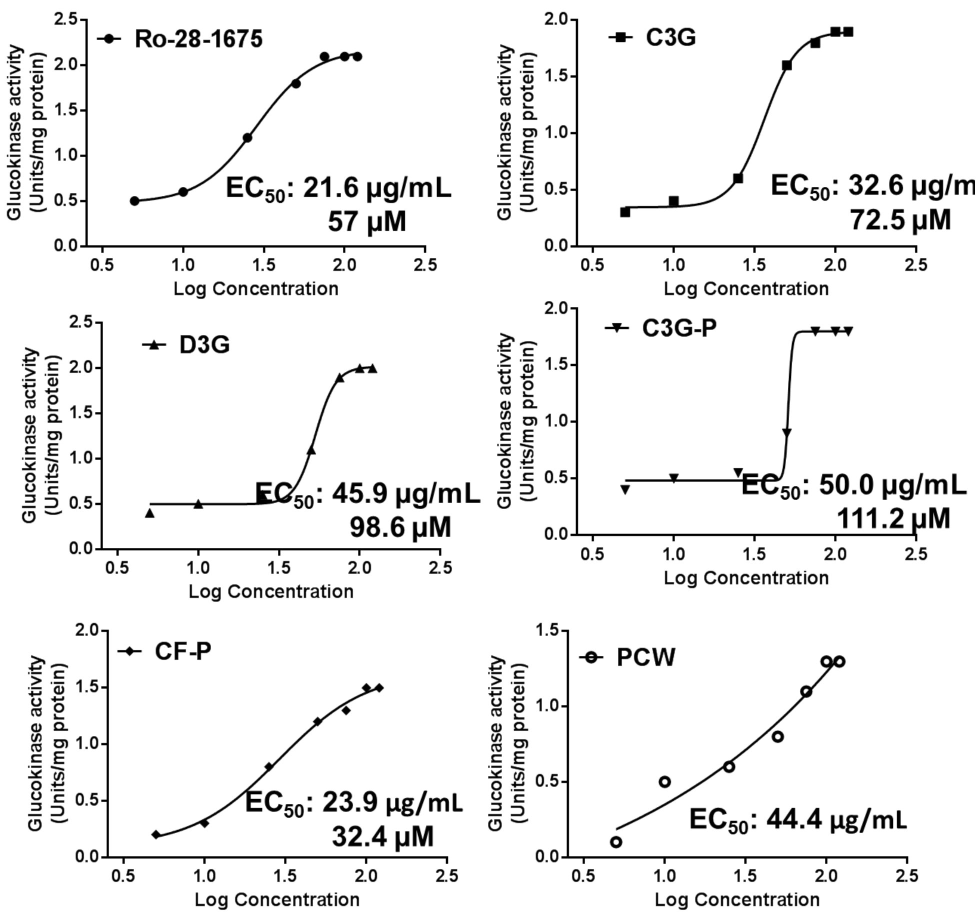
Effect of anthocyanins from purple corn on proteins related to FFAR1-dependent insulin secretion in iNS-1E cells

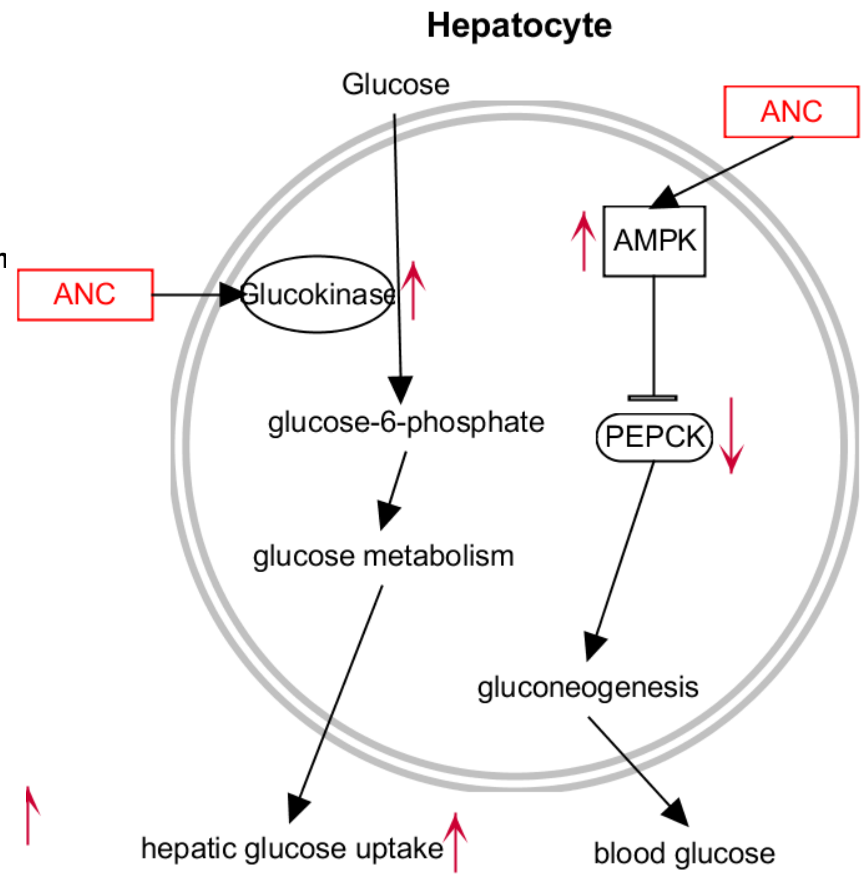




Luna-Vital & de Mejia, 2018. *PloS one*. 13(7), e0200449

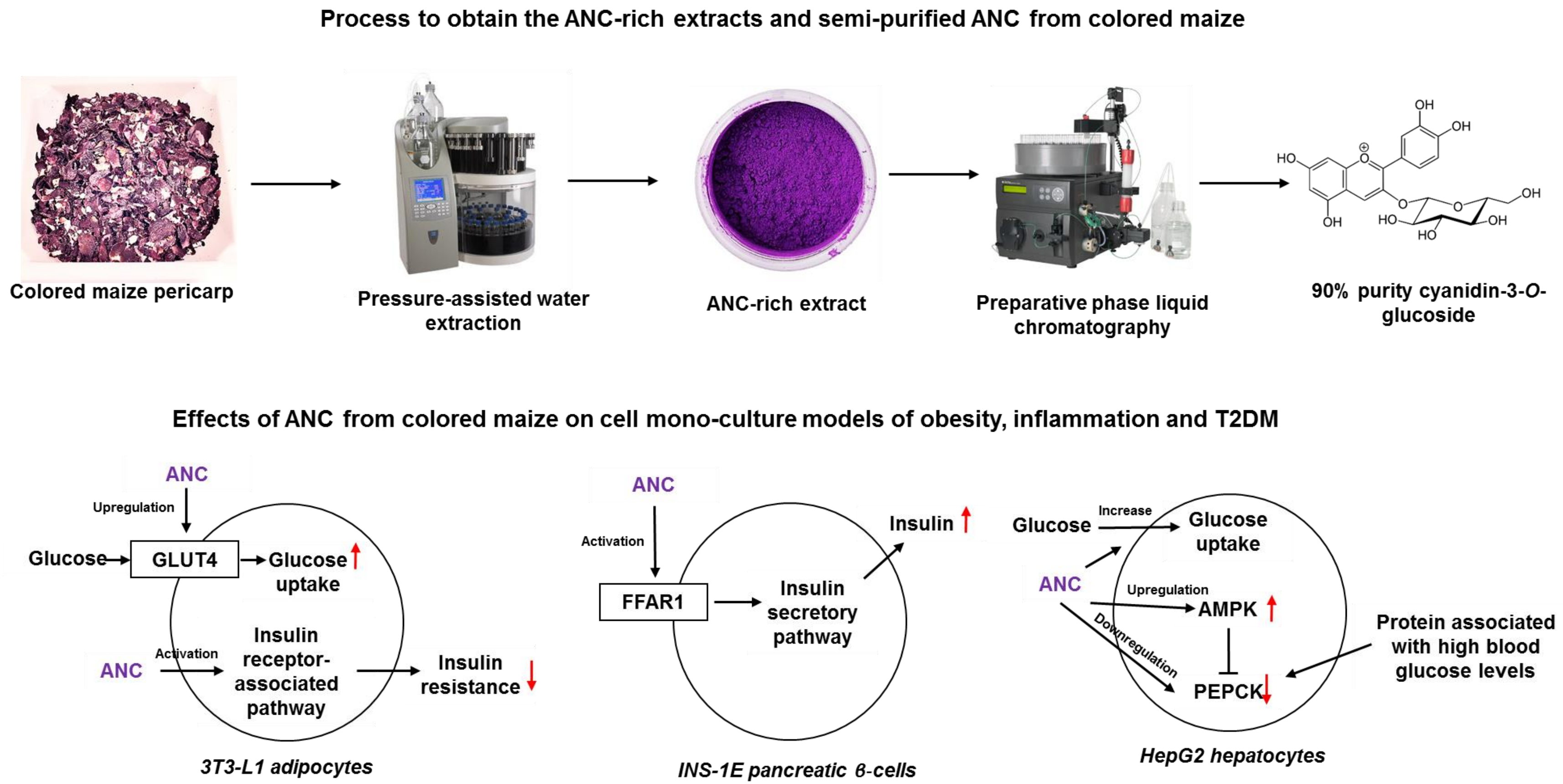
Effect of anthocyanins from purple corn on GK-activating potential in HepG2 cells





Luna-Vital & de Mejia, 2018. *PloS one*. 13(7), e0200449

In vitro studies using adipocytes, hepatocytes, and pancreatic cells have shown potential benefits improving metabolic disorders



Luna-Vital *et al.*, 2017. *Mol. Nutr. Food Res.* 61(12), 1700362

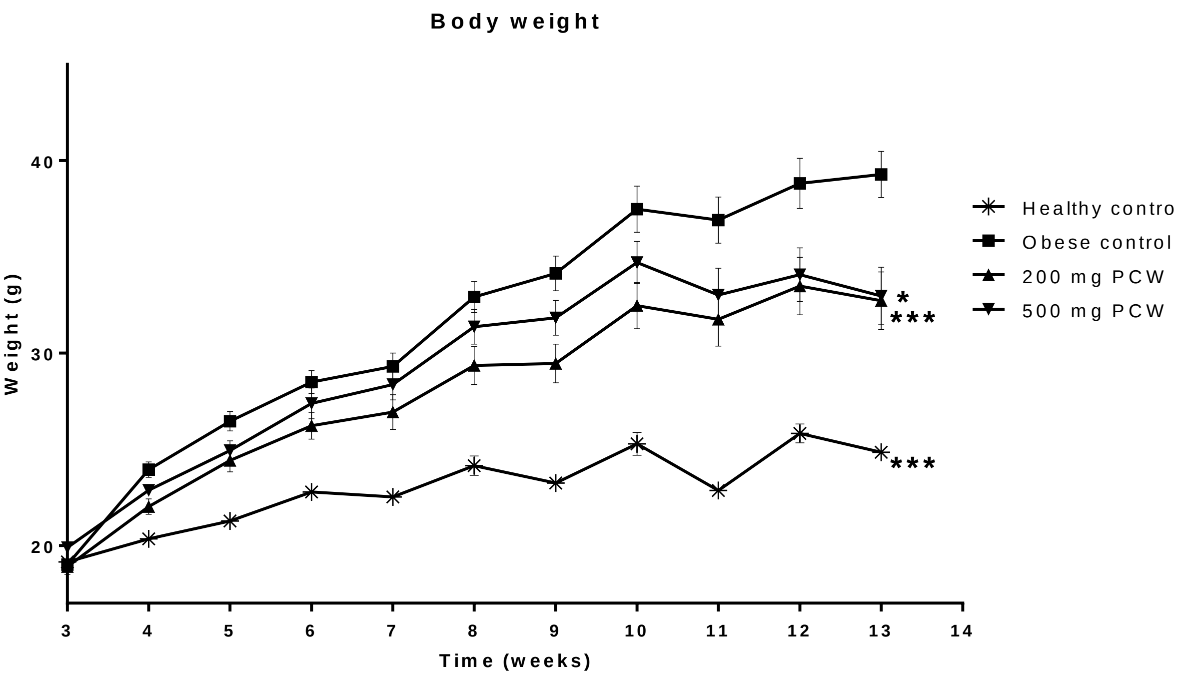
Luna-Vital & de Mejia, 2018. *PloS one.* 13(7), e0200449

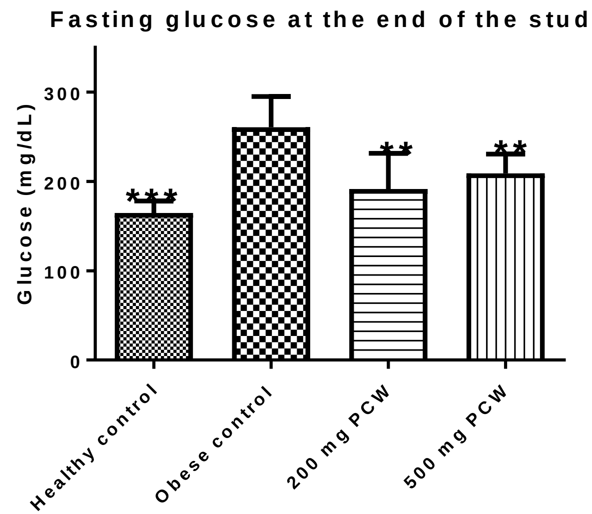
Conclusions related to diabetes

- Anthocyanins activated FFAR-1 in pancreatic cells.
- D3G was the most effective ANC, followed by C3G; the major ANC in PCW.
- The results of this study suggest that ACN from colored corn are good candidates to be incorporated in the diet during type-2 diabetes treatment.

Luna-Vital & de Mejia, 2018. *PloS one*. 13(7), e0200449

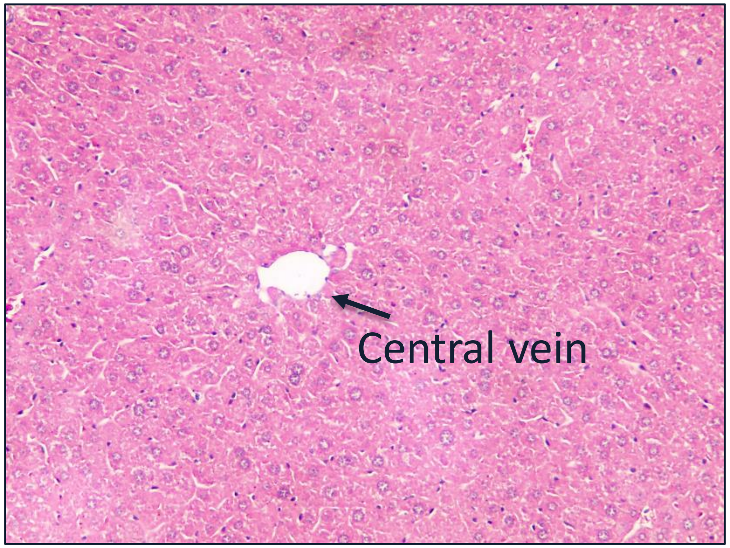
In an *in vivo* model of obesity, the anthocyanin-rich extract of purple corn prevented body weight gain and reduced fasting blood glucose



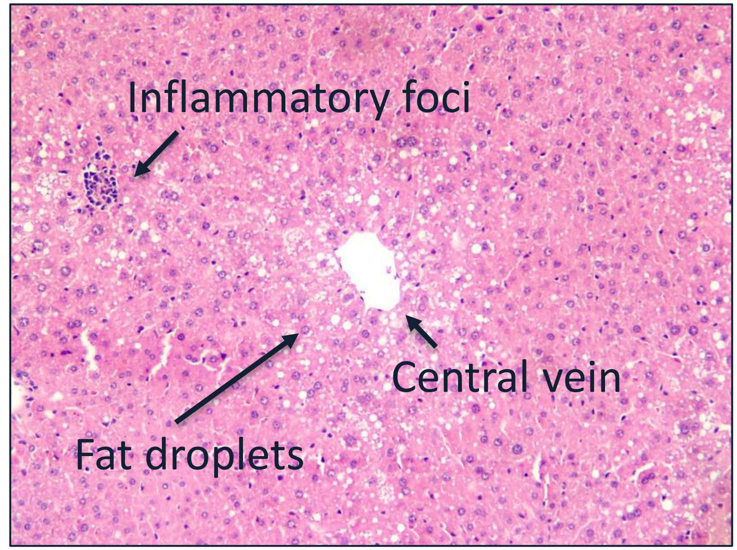


Luna-Vital & de Mejia, 2018. Unpublished results.

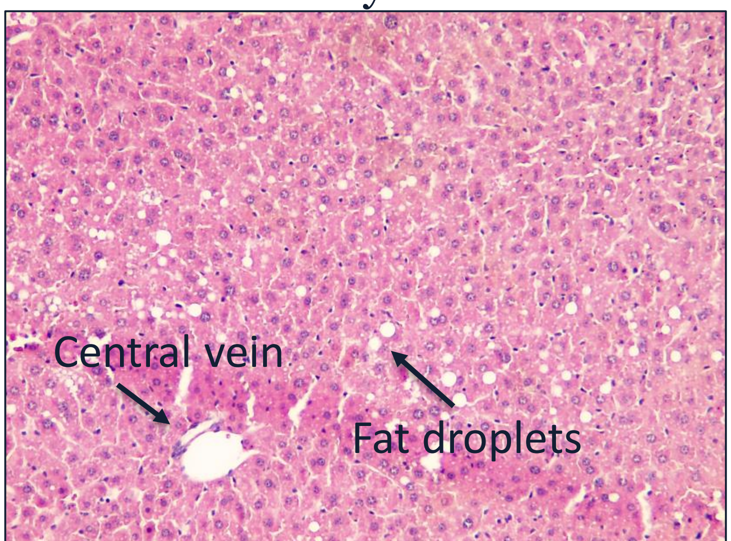
Anthocyanin rich extract reduced liver steatosis in HDF-fed mice



Healthy control



Obese control

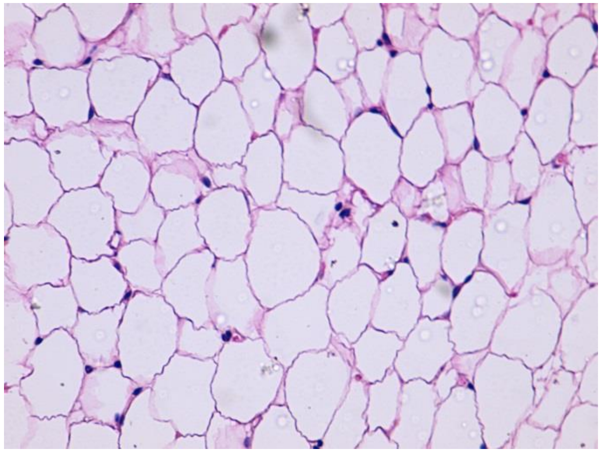


200 mg/kg PCW

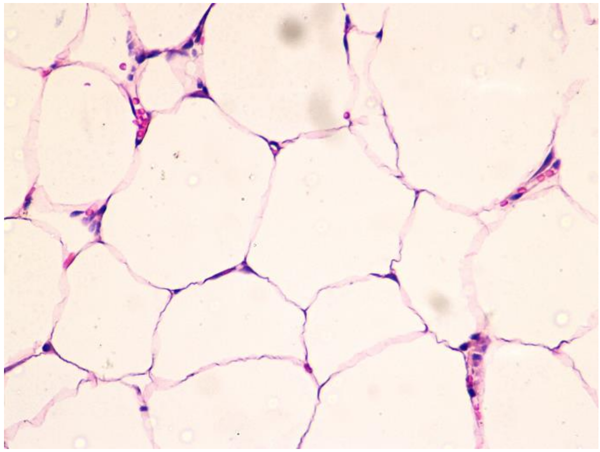
500 mg/kg PCW

Luna-Vital & de Mejia, 2018. Unpublished results.

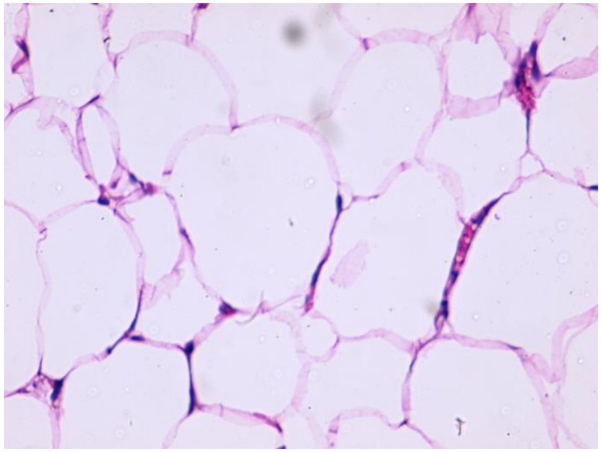
Anthocyanin-rich extract from purple corn reduced the lipid accumulation in adipocytes



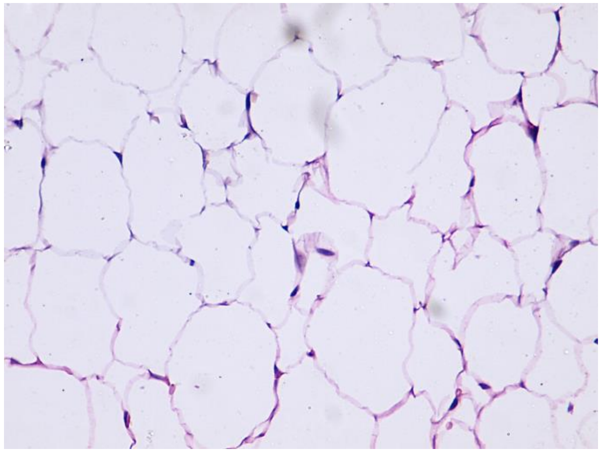
Healthy control



Obese control



200 mg/kg PCW



500 mg/kg PCW

Luna-Vital & de Mejia, 2018. Unpublished results.

Future Perspectives

- Correlation of the anthocyanin chemical composition of foods with the *in vitro* and *in vivo* potential to reduce chronic diseases.

- Effect of processing on the chemistry and composition of anthocyanins in foods and their human health impact.

- Databases of anthocyanin composition and concentration in different food sources.

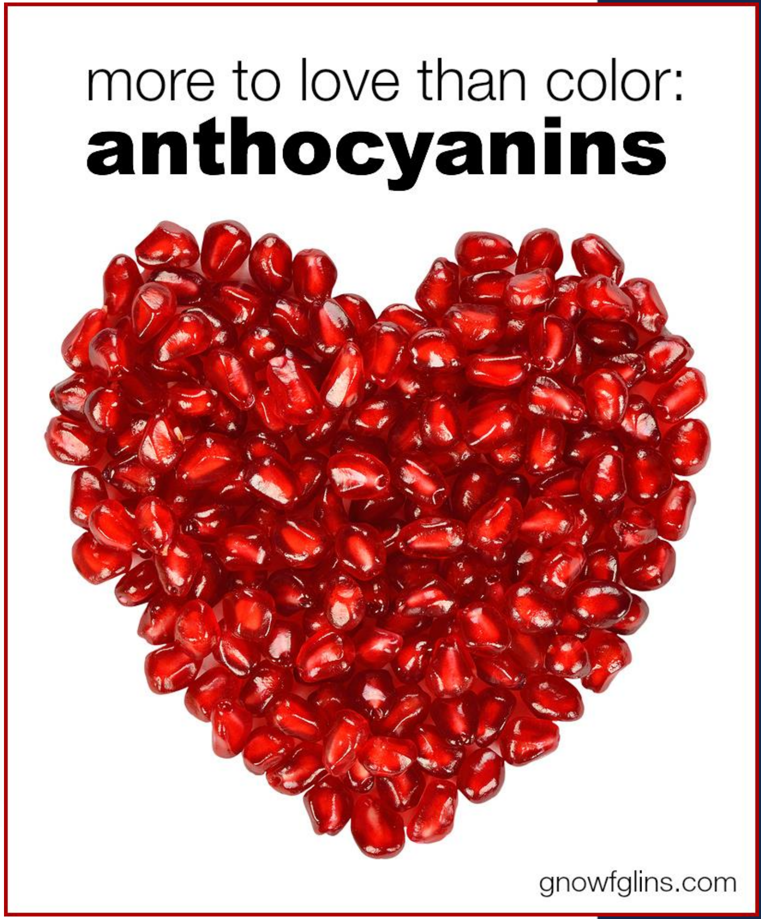
Take-home message

- Anthocyanins are compounds in foods that can be used by the food industry as natural pigments.

- Anthocyanins have potential to reduce obesity complications, and manage diabetes.

- The development of functional foods with value-added properties is of great interest to the scientific community and to the food industry.

Thank you!




Thank you