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[SmarterNaturally Explains]

GRextra for ATHLETIC PERFORMANCE, ENDURANCE & RECOVERY

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GRextra for Athletic Performance, Endurance & Recovery

Glucoraphanin is a natural molecule found in some plants - most notably broccoli. When these plants are eaten, glucoraphanin is converted into its active form - called sulforaphane - which is then absorbed by our gut. Sulforaphane then enters our cells and exerts several different metabolic effects, which together serve to boost our production of antioxidants, reduce inflammation, and improve our cell's ability to function, produce energy and repair damage.

GRextra is our super-strain of broccoli, which is a powerful source of sulforaphane.
For more details, including biological mechanisms of action, see our ***Guide to GRextra***

Due to the effects of sulforaphane in our cells, it has been extensively researched for its beneficial effects on human health across a range of different areas - including boosting athletic performance & recovery. Early-stage human, rodent and cell-culture studies suggest that increased exposure to sulforaphane could support athletic performance, recovery and resilience across a broad range of areas through optimising metabolism and energy production.

> "Sulforaphane can improve endurance capacity, decrease muscle fatigue, increase mitochondrial biogenesis, and prevent organ damage."
>
> *Review: Sulforaphane in Preventing Inflammation, Oxidative Stress & Fatigue (Ruhee et al, 2020)*

This makes glucoraphanin a valuable dietary nutrient for athletes looking to optimise their metabolism to support improved performance, endurance and recovery.

Summary of Research & Evidence

Below, we've summarised the key areas of research which are showing promising results for the potential of glucoraphanin & sulforaphane to support athletic health & performance, including:

1) Improved exercise performance & capacity
2) Reduced muscle soreness & improved muscle recovery
3) Protection of organs from oxidative damage during exercise
4) Greater muscle growth
5) Reduced body fat
6) Improved cardiovascular function
7) Improved joint health

1. Improved exercise performance & capacity

Administering glucoraphanin/sulforaphane has been found in animal studies to improve running endurance[1,2,3] and muscle power output[4] by up to 40%, whilst simultaneously reducing the level of biomarkers in the blood associated with muscle fatigue and damage by up to 60%[1,2,3,4].

> "Sulforaphane pretreatment enhanced exercise endurance under hypoxia." [13% increase]
> *Nrf2 Activation Enhances… Hypoxic Exercise Capacity*
> *(Wang et al. Med Sci Sports Exerc. 2020)*

This indicates that through mitigating oxidative and inflammatory damage during exercise, these natural molecules can help unlock increased performance and endurance whilst simultaneously protecting our muscles from the damage normally associated with intense exercise.

2. Reduced muscle soreness & improved muscle recovery

As well as protecting muscles from damage during exercise, administering glucoraphanin/sulforaphane has been found to help improve muscular recovery after exercise.

Studies have found these molecules improve recovery both at a physical level - through reducing the severity and duration of Delayed Onset Muscle Soreness (DOMS)[5] - and at a biological level, through reducing both the physical cellular damage to muscles and the levels of various biomarkers linked to muscle damage, oxidative stress, inflammation and pro-inflammatory cytokines[6,7,8,9].

> "Sulforaphane plays an indirect antioxidant role on the muscle by preventing muscle damage which intense exercise can cause."
> *Review: A Potential Strategy Against… Muscular Damage during Sports Activity*
> *(Brancaccio et al. 2020)*

This indicates that these molecules can help protect muscles from damage following as well as during exercise, and support faster and more effective recovery from exercise at both the muscular and cellular level.

3. Protection of organs from oxidative damage during exercise

Intense exercise can impact on the health of our organs as well as our muscles. Through the anti-inflammatory and antioxidant pathways it activates, studies have found that administering glucoraphanin/sulforaphane can help protect organs throughout the body (including the liver[10], kidneys[11], and heart/cardiovascular system[11,12,13,14,15,16]) from oxidative damage and cell death during periods of intense exercise.

> "The sulforaphane + exercise group showed a significant reduction in the expression of cytokines and blood biomarkers of tissue damage or cell death"
> *Protective Effects of Sulforaphane on Exercise-Induced Organ Damage…*
> *(Ruhee et al. Antioxidants (Basel), 2020)*

This indicates the value of these compounds to the broader potential for supporting recovery and protecting the long-term health of athletes more generally, beyond just their muscles.

4. Greater muscle growth

Studies have found that administering glucoraphanin/sulforaphane can increase muscle mass and strength through a variety of mechanisms.

These include activating anti-oxidant gene pathways[17,18,19]; suppressing the production of myostatin[20,21] (a protein which limits muscle growth), inducing the production of myogenin[20,22] (a protein which stimulates muscle growth) in muscle tissue; and stimulating the growth of satellite cells, which are the stem cells required for skeletal muscle growth[21,23].

> "Sulforaphane improves grip strength, exercise performance, and numbers of skeletal muscle stem cells"
> *Sulforaphane prevents age-associated cardiac and muscular dysfunction…*
> *(Bose et al. Aging Cell. 2020)*

Together, these various mechanisms point to significant added value to athletes looking to boost muscle growth via tuning the body's natural muscle growth regulation mechanisms though adding these natural molecules to their diet.

5. Reduced body fat

Through driving changes in metabolism, studies have indicated that glucoraphanin/sulforaphane can significantly reduce body weight through reducing fat levels[24,25] in several ways.

These include reversing leptin & insulin resistance[26,27,28], stimulating mitochondrial growth[29] and the conversion of inert energy-storing 'white fat' to metabolically-active 'brown fat'[30,31], driving the breakdown of fat droplets inside cells[32,33], and improving the metabolism of sugar and fat.[26,34]

Randomised-controlled trials in humans have supported this by showing that glucoraphanin supplements can improve the results from weight-loss exercise programmes[35].

> "Sulforaphane reduced body weight and liver weight significantly in our ten trials."
> *Review: Sulforaphane ameliorates lipid profile in rodents (Du et al, 2021)*

Together, these mechanisms indicate several redundant ways that these molecules drive the reduction of body fat, offering performance benefits to athletes.

6. Improved cardiovascular function

As well as protecting our heart and cardiovascular system from exercise-induced damage, studies have found that glucoraphanin/sulforaphane can also support our cardiovascular function and health over the long term in several key areas.

These include lowering blood pressure [36,37], reducing "bad" cholesterol (LDL) levels in the blood[38], slowing the loss of heart function that naturally occurs as we age[39], and may even reduce the risk of serious cardiovascular events such as stroke[40].

> "Sulforaphane supplementation improved the ejection fraction, fractional shortening, and stroke volume."
> *Sulforaphane prevents age-associated cardiac and muscular dysfunction…*
> *(Bose et al. Aging Cell. 2020)*

This means that these natural molecules can both help protect our cardiovascular system from both short-term exercise-induced damage and promote long-term cardiac health, enabling athletes to unlock peak cardiovascular performance for longer.

7. Improved joint health

There is a growing body of research indicating that glucoraphanin/sulforaphane can help support joint and bone health - often of critical importance for athletes.

Specifically, studies have found that sulforaphane can help reduce joint inflammation[41], protect the cartilage inside joints from degradation[41,42,43,44], and improve bone health & strength[45,46]. Initial studies also suggest these molecules may help to reduce the risk/severity of arthritic joint conditions, including osteo-[47,48] and rheumatoid[49,50] arthritis.

> "Sulforaphane may be a candidate therapeutic agent for treatment of cartilage degradation in arthritides."
> *Phase 2 enzyme inducer sulphoraphane… inhibits cartilage matrix degradation (Kim et al. Rheumatology (Oxford). 2012)*

Athletes put additional strain on their joints through intense exercise, leading to a greater risk of injury and long-term damage to and conditions of their joints (including an increased risk of developing arthritis). These natural molecules therefore offer promise to athletes, both for reducing short-term injury risk and supporting improved long-term joint health.

About SmarterNaturally

GRextra is a unique delivery vector for glucoraphanin. It was developed over decades of research, is backed by patented research from the Quadram Institute and clinical trials run with NHS hospitals, supported by public research grants from Innovate UK.

We use it to create the most powerful, convenient and cost-effective solutions on the market for accessing the health benefits of sulforaphane. For example, SmarterNaturally SuperSoup contains a once-weekly dose of glucoraphanin - as much as 5 heads of raw broccoli or 14 tablets of a leading glucoraphanin supplement.

Our products are also rich in other nutrients, such as dietary fibre and Vitamins C & B6, calcium and folic acid, which help support our metabolism, bone health, energy production, the reduction of fatigue and our immune system - further boosting our health.

References

1. Nrf2 Activation Enhances Muscular MCT1 Expression and Hypoxic Exercise Capacity *(Wang et al. Med Sci Sports Exerc. 2020)*
2. Nuclear factor (erythroid derived 2)-like 2 activation increases exercise endurance capacity via redox modulation in skeletal muscles *(Oh et al. Sci Rep. 2017)*
3. Sulforaphane enhances Nrf2-mediated antioxidant responses of skeletal muscle induced by exhaustive exercise in HIIT mice *(Wang et al. Food Sci Human Well. 2022)*
4. Sulforaphane alleviates muscular dystrophy in mdx mice by activation of Nrf2 *(Sun et al. J Appl Physiol. 2015)*
5. Effect of a sulforaphane supplement on muscle soreness and damage induced by eccentric exercise in young adults: A pilot study *(Komine et al. Physiol Rep. 2021)*
6. Oral chronic sulforaphane effects on heavy resistance exercise: Implications for inflammatory and muscle damage parameters in young practitioners *(Sato et al. Nutrition. 2021)*
7. Sulforaphane treatment protects skeletal muscle against damage induced by exhaustive exercise in rats *(Malaguti et al. J Appl Physiol. 2009)*
8. Protective Effects of Sulforaphane on Exercise-Induced Organ Damage via Inducing Antioxidant Defense Responses *(Ruhee et al. Antioxidants (Basel). 2020)*
9. Sulforaphane Attenuates Muscle Inflammation in Dystrophin-deficient mdx Mice via NF-E2-related Factor 2 (Nrf2)-mediated Inhibition of NF-κB Signaling Pathway *(Sun et al. J Biol Chem. 2015)*
10. Protective Effects of Sulforaphane on Exercise-Induced Organ Damage via Inducing Antioxidant Defense Responses *(Ruhee et al. Antioxidants (Basel). 2020)*
11. Dietary approach to attenuate oxidative stress, hypertension, and inflammation in the cardiovascular system (*Wu et al. Proc Natl Acad Sci U S A. 2004)*
12. Modulation of Phase II Enzymes by Sulforaphane: Implications for Its Cardioprotective Potential *(Angeloni et al. I. J Agric Food Chem. 2009)*
13. Potent Induction of Total Cellular and Mitochondrial Antioxidants and Phase 2 Enzymes by Cruciferous Sulforaphane in Rat Aortic Smooth Muscle Cells: Cytoprotection Against Oxidative and Electrophilic Stress *(Zhu et al. Cardiovasc Toxicol. 2008)*
14. Sulforaphane effects on oxidative stress parameters in culture of adult cardiomyocytes *(Corsacc et al. Biomed Pharmacother. 2018)*
15. Cruciferous Vegetable Phytochemical Sulforaphane Affects Phase II Enzyme Expression and Activity in Rat Cardiomyocytes through Modulation of Akt Signaling Pathway *(Leoncini et al. J Food Sci. 2011)*
16. 17β-Estradiol enhances sulforaphane cardioprotection against oxidative stress *(Angeloni et al. J Nutr Biochem. 2017)*
17. Sulforaphane prevents age-associated cardiac and muscular dysfunction through Nrf2 signaling *(Bose et al. Aging Cell. 2020)*
18. Sulforaphane protects against skeletal muscle dysfunction in spontaneous type 2 diabetic db/db mice *(Wang et al. Life Sci. 2020)*
19. Sulforaphane mitigates muscle fibrosis in mdx mice via Nrf2-mediated inhibition of TGF-β/Smad signaling *(Sun et al. J Appl Physiol. 2016)*
20. Sulforaphane prevents dexamethasone-induced muscle atrophy via regulation of the Akt/Foxo1 axis in C2C12 myotubes *(Son et al. Biomed Pharmacother. 2017)*
21. Sulforaphane causes a major epigenetic repression of myostatin in porcine satellite cells *(Fan et al. Epigenetics. 2012)*
22. Sulforaphane reduces lipopolysaccharide-induced inflammation and enhances myogenic differentiation of mouse embryonic myoblasts via the toll-like receptor 4 and NLRP3 pathways *(Wang et al. Adv Clin Exp Med. 2023)*
23. Sulforaphane Enhanced Proliferation of Porcine Satellite Cells via Epigenetic Augmentation of SMAD7 *(Zhang et al. Animals (Basel). 2022)*
24. Sulforaphane ameliorates lipid profile in rodents: an updated systematic review and meta-analysis *(Du et al. Sci Rep. 2021)*
25. Sulforaphane attenuates obesity by inhibiting adipogenesis and activating the AMPK pathway in obese mice *(Choi et al. J Nutr Biochem. 2014)*
26. Sulforaphane reduces obesity by reversing leptin resistance *(Cakir et al. Elife. 2022)*
27. Sulforaphane Regulates Glucose and Lipid Metabolisms in Obese Mice by Restraining JNK and Activating Insulin and FGF21 Signal Pathways *(Tian et al. J Agric Food Chem. 2021)*

28. Sulforaphane improves leptin responsiveness in high-fat high-sucrose diet-fed obese mice *(Shawky et al. Eur J Pharmacol. 2018)*
29. Sulforaphane Improves Lipid Metabolism by Enhancing Mitochondrial Function and Biogenesis In Vivo and In Vitro *(Lei et al. Mol Nutr Food Res. 2019)*
30. Glucoraphanin Ameliorates Obesity and Insulin Resistance Through Adipose Tissue Browning and Reduction of Metabolic Endotoxemia in Mice *(Nagata et al. Diabetes. 2017)*
31. The Protective Effects of Sulforaphane on High-Fat Diet-Induced Obesity in Mice Through Browning of White Fat *(Liu et al. Front Pharmacol. 2021)*
32. Sulforaphane induces lipophagy through the activation of AMPK-mTOR-ULK1 pathway signalling in adipocytes *(Masuda et al. J Nutr Biochem. 2022)*
33. Modulation of Adipocyte Differentiation and Proadipogenic Gene Expression by Sulforaphane, Genistein, and Docosahexaenoic Acid as a First Step to Counteract Obesity (*Valli et al. Oxid Med Cell Longev. 2018)*
34. Targeting PLIN2/PLIN5-PPARγ: Sulforaphane Disturbs the Maturation of Lipid Droplets *(Tian et al. Mol Nutr Food Res. 2019)*
35. The Effects of Aerobic-Resistance Training and Broccoli Supplementation on Plasma Dectin-1 and Insulin Resistance in Males with Type 2 Diabetes *(Saeidi et al. Nutrients. 2021)*
36. Broccoli Sprouts Promote Sex-Dependent Cardiometabolic Health and Longevity in Long-Evans Rats *(Noble et al. Int J Environ Res Public Health. 2022)*
37. Dietary approach to attenuate oxidative stress, hypertension, and inflammation in the cardiovascular system *(Wu et al. Proc Natl Acad Sci U S A. 2004)*
38. Diet rich in high glucoraphanin broccoli reduces plasma LDL cholesterol: Evidence from randomised controlled trials *(Armah et al. Mol Nutr Food Res. 2015)*
39. Sulforaphane prevents age-associated cardiac and muscular dysfunction through Nrf2 signaling *(Bose et al. Aging Cell. 2020)*
40. Fruit and vegetable intake in relation to risk of ischemic stroke *(Joshipura et al. JAMA. 1999)*
41. Sulforaphane Represses Matrix-Degrading Proteases and Protects Cartilage From Destruction In Vitro and In Vivo *(Davidson et al. Arthritis Rheum. 2013)*
42. Sulforaphane-loaded hyaluronic acid-poloxamer hybrid hydrogel enhances cartilage protection in osteoarthritis models *(Monteiro do Nascimento et al. Mater Sci Eng C Mater Biol Appl. 2021)*
43. Phase 2 enzyme inducer sulphoraphane blocks prostaglandin and nitric oxide synthesis in human articular chondrocytes and inhibits cartilage matrix degradation *(Kim et al. Rheumatology (Oxford). 2012)*
44. Natural ingredients-derived antioxidants attenuate H(2)O(2)-induced oxidative stress and have chondroprotective effects on human osteoarthritic chondrocytes via Keap1/Nrf2 pathway *(Yang et al. Free Radic Biol Med. 2020)*
45. High bone mass in mice can be linked to lower osteoclast formation, resorptive capacity, and restricted in vitro sensitivity to inhibition by stable sulforaphane *(Louka et al. Cell Biochem Funct. 2022)*
46. Anabolic and Antiresorptive Modulation of Bone Homeostasis by the Epigenetic Modulator Sulforaphane, a Naturally Occurring Isothiocyanate *(Thaler et al. J Biol Chem. 2016)*
47. Stable sulforaphane protects against gait anomalies and modifies bone microarchitecture in the spontaneous STR/Ort model of osteoarthritis *(Davidson et al. Ann Rheum Dis. 2023)*
48. Stable sulforaphane protects against gait anomalies and modifies bone microarchitecture in the spontaneous STR/Ort model of osteoarthritis *(Javahari et al. Bone. 2017)*
49. Inhibition of Synovial Hyperplasia, Rheumatoid T Cell Activation, and Experimental Arthritis in Mice by Sulforaphane, a Naturally Occurring Isothiocyanate *(Kong et al. Am J Epidemiol. 2003)*
50. Sulforaphane has opposing effects on TNF-alpha stimulated and unstimulated synoviocytes *(Fragoulis et al. Arthritis Res Ther. 2012)*

Sulforaphane & Athletic Performance, Endurance & Recovery

Dossier of Supporting Evidence

SmarterNaturally's products are all made using GRextra - our unique super-broccoli which contains ~5x more glucoraphanin than traditional varieties of broccoli, as well as other bioactive molecules including indole-3-carbinol, quercetin and kaempferol.

Glucoraphanin is a natural health-boosting molecule. When converted into its active form (called sulforaphane) in our gut, it has powerful effects on our metabolism, driving our body's natural anti-oxidant (Nrf2) and anti-inflammatory (anti-NFkB) responses to boost our health, as well as promoting cell resilience and survival through triggering heat-shock and other related pathways.

Through these pathways, there is now a growing body of evidence that these molecules can support the full cycle of activity for athletes and active consumers alike - including boosting performance, improving recovery, optimising muscle/fat body composition, and supporting the long-term health of athletes.

Research studies have specifically linked glucoraphanin & sulforaphane to:

1. Increased Exercise Capacity

Administering glucoraphanin/sulforaphane has been found to improve running endurance and muscle power output in mice, and reduce the level of biomarkers in the blood associated with muscle fatigue and damage - largely through activation of the anti-inflammatory Nrf2 gene pathway.

[REVIEW] The Integrative Role of Sulforaphane in Preventing Inflammation, Oxidative Stress and Fatigue: A Review of a Potential Protective Phytochemical
Ruhee et al. Antioxidants (Basel). 2020 Feb 4;9(2):136
(doi: 10.3390/antiox9020136)

"SFN can improve endurance capacity, decrease muscle fatigue, increase mitochondrial biogenesis, and prevent organ damage via inducing enzymatic pathways."

Nrf2 Activation Enhances Muscular MCT1 Expression and Hypoxic Exercise Capacity
Wang et al. Med Sci Sports Exerc. 2020 Aug;52(8):1719-1728
(doi: 10.1249/MSS.0000000000002312)

Dosage = 25 mg/kg SFN via intraperitoneal injection four times in three days (72, 48, 24, and 3h before exercise)

- "The results indicated that sulforaphane pretreatment enhanced the exercise endurance under hypoxia" [13% increase]
- "The expressions of LDH-B and LDH activity of converting lactate into pyruvate, as well as citrate synthase activity were significantly higher, whereas the LDH activity of converting pyruvate into lactate and blood lactate level were remarkably lower in the sulforaphane-exercise mice than those of the phosphate-buffered saline–exercise group."
- "Nrf2 activation by sulforaphane pretreatment induced a significant increase in the expression of MCT1 and CD147, but not MCT4, in mouse skeletal muscle"

Nuclear factor (erythroid derived 2)-like 2 activation increases exercise endurance capacity via redox modulation in skeletal muscles
Oh et al. Sci Rep. 2017 Oct 10;7(1):12902
(doi: 10.1038/s41598-017-12926-y)

Dosage = 25 mg/kg SFN via intraperitoneal injection four times in three days (72, 48, 24, and 3h before exercise)

- "Nrf2+/+[sulforaphane] mice achieved greater running distances than those of Nrf2+/+[control] mice" [38% increase]
- "TBARS levels in sulforaphane-injected Nrf2+/+ mice were lower than those of uninjected Nrf2+/+ mice" at 18h post exercise [0.73 v 1.07 uM/MDA/mg, $p<0.01$]
- "CPK levels in Nrf2+/+[sulforaphane] mice were significantly lower compared with other treatment groups."
- "We did not see a significant increase in blood lactate levels in Nrf2+/+ mice with sulforaphane injection after 50 minutes, unlike in other groups."
- "Sulforaphane injection in Nrf2+/+ mice exerted protective effects in muscle under exhaustive exercise conditions."

Sulforaphane enhances Nrf2-mediated antioxidant responses of skeletal muscle induced by exhaustive exercise in HIIT mice
Wang et al. Food Sci Human Well. 2022;11(5):1355-1361
(doi: 10.1016/j.fshw.2022.04.035)

Dosage = 25 mg/kg SFN via intraperitoneal injection four times in three days (72, 48, 24, and 3h before exercise)

- "HIIT and HIIT+sulforaphane groups could run longer and farther than the control group, but the differences with the performance of the control group were not statistically significant"
  - *Running distance, SFN mice 1300m vs CON mice 1200m (ns); 8% increase*
- "HIIT + sulforaphane group had a significantly lower whole blood CK level and the expression of muscle 4HNE-modified protein than those of the HIIT group"
- "Moreover, sulforaphane treatment significantly increased the mRNA expression of Nrf2, Cat, and Nqo1 in skeletal muscle of the HIIT + sulforaphane group, compared with the HIIT group"
- "HIIT + sulforaphane treatment significantly increased the expression of Nrf2 nucleoprotein and antioxidant proteins (CAT, HMOX1 and SOD2) of mice skeletal muscle, compared to the HIIT group"
- "sulforaphane treatment strongly increased muscular mRNA levels of these genes in the HIIT + sulforaphane group, compared with those of the HIIT group" [muscular key enzyme genes in GSH biosynthesis (Gss, Gsr, Gclc, and Gclm)]"

Sulforaphane alleviates muscular dystrophy in mdx mice by activation of Nrf2
Sun et al. J Appl Physiol (1985). 2015 Jan 15;118(2):224-37.
(doi: 10.1152/japplphysiol.00744.2014)

Dosage = 2 mg/kg SFN via daily oral gavage for 8 weeks

- “Sulforaphane significantly increased skeletal muscle mass, muscle force (30%), running distance (20%), and GSH-to-GSSG ratio (3.2-fold) of mdx mice and decreased the activities of plasma creatine phosphokinase (45%) and lactate dehydrogenase (40%), gastrocnemius hypertrophy (25%), myocardial hypertrophy (20%), and malondialdehyde levels (60%).”
- “Collectively, these results show that sulforaphane can improve muscle function and pathology and protect dystrophic muscle from oxidative damage in mdx mice associated with Nrf2 signaling pathway”

2. Improved Muscle Recovery

Administering glucoraphanin/sulforaphane has been found to help improve muscular recovery after exercise, including through reducing the severity and duration of Delayed Onset Muscle Soreness (DOMS) and reduced levels of biomarkers in muscles and the blood associated with muscle damage, oxidative stress, inflammation and pro-inflammatory cytokines.

[REVIEW] Dietary Thiols: A Potential Supporting Strategy against Oxidative Stress in Heart Failure and Muscular Damage during Sports Activity
Brancaccio et al. Int J Environ Res Public Health. 2020 Dec 16;17(24):9424
(doi: 10.3390/ijerph1724942)

“These data suggest that the administration of SFN plays an indirect antioxidant role on the muscle by preventing muscle damage which intense exercise can cause.”

[REVIEW] Phytochemicals in Skeletal Muscle Health: Effects of Curcumin (from Curcuma longa Linn) and Sulforaphane (from Brassicaceae) on Muscle Function, Recovery and Therapy of Muscle Atrophy
Vargas et al. Plants (Basel). 2022 Sep 26;11(19):2517
(doi: 10.3390/plants11192517)

“In different models of muscle damage, including pathological or exhaustive exercise, curcumin and SFN have proven to be effective in preventing or reducing injuries to skeletal muscle mass by their investment in the promotion of the signalling pathways involved in cytoprotection and optimal antioxidant response. Both bioactive compounds efficiently blunt inflammation and help to recover skeletal muscle.”

Effect of a sulforaphane supplement on muscle soreness and damage induced by eccentric exercise in young adults: A pilot study
Komine et al. Physiol Rep. 2021 Dec;9(24):e15130
(doi: 10.14814/phy2.15130)

Dosage = 30 mg GR a day (10mg x3 times a day) for 2 weeks and 4 days

- "Subjective muscle soreness was analyzed by VAS. The VAS on palpation of control groups peaked at 2 days after exercise. On the other hand, the VAS of sulforaphane group peaked at 1 day after exercise"
- "The sulforaphane group showed a significantly lower VAS on palpation at 2 days
- after exercise than the control group"
- "The decrease in elbow range of movement at 2 days after exercise was suppressed in the sulforaphane group compared with the control group."
- "In the sulforaphane group, the serum MDA concentration was significantly lower at 2 days after exercise compared to the control group"
- "TBARS levels peaked after 2 days of exercise and were significantly lower in the sulforaphane group, suggesting that sulforaphane intake suppressed exercise-induced oxidative stress."

Oral chronic sulforaphane effects on heavy resistance exercise: Implications for inflammatory and muscle damage parameters in young practitioners
Sato et al. Nutrition. 2021 Oct;90:111266
(doi: 10.1016/j.nut.2021.111266)

Dosage = 30 mg oral SFN per day for 4 weeks

- "Vigorous resistance exercise–induced increase in biomarkers of muscle damage may be ameliorated by oral chronic intake of sulforaphane"
- "The exercise-induced increase in CK levels was suppressed 24 h after exercise after the administration of sulforaphane" [CK is a biomarker for muscle damage]
- "IL-6 levels increased 30 min after exercise in both groups, sulforaphane intake suppressed the exercise-induced increase in IL-6 as compared with that in the placebo group"

Sulforaphane treatment protects skeletal muscle against damage induced by exhaustive exercise in rats

Malaguti et al. J Appl Physiol (1985). 2009 Oct;107(4):1028-36
(doi: 10.1152/japplphysiol.00293.2009)

Dosage = 25 mg/kg SFN via intraperitoneal injection 3 times in 3 days (72, 48, and 24h before exercise)

- [In mice that ran on a treadmill until exhaustion]
- "Plasma LDH and CPK activities of the exercise+sulforaphane group was comparable with that of the control group, as evidenced by the ability of sulforaphane to counteract acute exhaustive exercise-induced muscle damage"
- "TBARS levels were significantly higher in the exercise group, and the levels of the sulforaphane and exercise+sulforaphane groups were comparable with those of the control group"
- "In the exercise group, acute exhaustive exercise significantly decreased the TAA activity level with respect to the control group.Sulforaphane treatment was able to significantly increase TAA activity in animals in the sulforaphane group and to maintain the TAA activity of animals in the exercise+sulforaphane group at the same level of the control group"
- "The histological analysis clearly demonstrated that exhaustive exercise caused myofibrillar damage. Sulforaphane treatment was able to prevent these muscle lesions, preserving myofibrillar organisation"

Protective Effects of Sulforaphane on Exercise-Induced Organ Damage via Inducing Antioxidant Defence Responses

Ruhee et al. Antioxidants (Basel). 2020 Feb 4;9(2):136
(doi: 10.3390/antiox9020136)

Dosage = 50 mg/kg SFN administered orally once before exercise

- "Sulforaphane treatment improves the Nrf2-mediated antioxidant defense responses of skeletal muscle induced by exhaustive exercise in the HIIT mice"

Sulforaphane Attenuates Muscle Inflammation in Dystrophin-deficient mdx Mice via NF-E2-related Factor 2 (Nrf2)-mediated Inhibition of NF-κB Signaling Pathway

Sun et al. J Biol Chem. 2015 Jul 17;290(29):17784-17795
(doi: 10.1074/jbc.M115.655019)

Dosage = 2 mg/kg SFN via daily oral gavage for 4 weeks

- "Sulforaphane treatment increased the expression of muscle phase II enzyme heme oxygenase-1 in an Nrf2-dependent manner"
- "Sulforaphane enhances the sarcolemmal integrity of mdx mice."
- "Sulforaphane treatment decreased the percent of total immune cell infiltration by 62%, 42%, and 65% in GAS, TB, and TA, in comparison with mdx counterparts ($p<0.05$)."

3. Protection against oxidative damage

Intense exercise can impact on the health of our organs as well as our muscles. Through the anti-inflammatory and antioxidant pathways it activates, initial studies have found that glucoraphanin/sulforaphane could help protect organs from oxidative damage during periods of intense exercise.

Protective Effects of Sulforaphane on Exercise-Induced Organ Damage via Inducing Antioxidant Defense Responses
Ruhee et al. Antioxidants (Basel). 2020 Feb 4;9(2):136
doi: 10.3390/antiox9020136.

Dosage = 50 mg/kg SFN administered orally once before exercise

- "Sulforaphane plus exercise group showed a significant reduction in the expression of cytokines and blood biomarkers of tissue damage or cell death"
- "However, there was a significantly less induction in all three biomarkers [AST, ALT, LDH] in the exercise + sulforaphane group compared to the exercise group alone ($p < 0.05$)."
- "TNFa and IL-1B mRNA expression levels. The exercise group showed increased mRNA expression by 2.3- and 5.1-fold, respectively, while the exercise + sulforaphane group showed less expression, showing changes of 1- and 3.2-fold, respectively"
- "mRNA expression of SOD1, CAT, and GPx1 enzymes was significantly upregulated by 2-, 1.5-, and 2.5-fold with exercise in the sulforaphane group"
- "Nrf2 mRNA expression was increased by 1.5-fold with sulforaphane in the exercise group, which differs significantly as compared to the exercise and/or sedentary sulforaphane groups"
- "Here, we presented data on the protective role of sulforaphane on acute exercise-induced liver damage. Collectively, we summarized that sulforaphane is not directly involved in the ROS reduction process, but it induces a cellular defense system through the induction of antioxidant enzymes via the upregulation of the Nrf2/HO-1 signal transduction pathway, thereby reducing oxidative stress and inflammation."

Dietary approach to attenuate oxidative stress, hypertension, and inflammation in the cardiovascular system
Wu et al. Proc Natl Acad Sci U S A. 2004 May 4;101(18):7094-9.
(doi: 10.1073/pnas.0402004101)

Dosage = 200 mg air-dried broccoli sprouts (containing approx. 12 umol of GR per gram) fed daily for 14 weeks (2.4 umol GR per day)

- "Our results show that intake of broccoli sprouts high in Grn, whose metabolite sulforaphane is a potent phase 2 protein inducer, decreased oxidative stress and inflammation in kidneys and the cardiovascular system. The promotion of cardiovascular function is similar to that seen with long-term consumption of pharmacological antioxidants."

Effect of broccoli extract enriched diet on liver cholesterol oxidation in rats subjected to exhaustive exercise
Cardenia et al. J Steroid Biochem Mol Biol. 2017 May;169:137-144
(doi: 10.1016/j.jsbmb.2016.04.005)

Dosage = Broccoli-Max 400mg capsules containing 1.2mg SFN for 45 days before an exhaustive treadmill exercise (0.55 mg/kg SFN)

- "Rats fed the BE-enriched diet showed a significantly reduced LDH plasma level, indicating that BE was able to prevent exercise-induced tissue damage. The cumulative effects of BE treatment on phase 2 antioxidant enzyme activities suggest that BE is able to counteract exercise-promoted oxidative stress, by inducing important antioxidant enzymes."

Modulation of Phase II Enzymes by Sulforaphane: Implications for Its Cardioprotective Potential
Angeloni et al. J Agric Food Chem. 2009 Jun 24;57(12):5615-22
(doi: 10.1021/jf900549c)

Dosage = 5 uM SFN for 30 mins to 48 h

- "A number of phase II enzymes can be induced in cultured cardiomyocytes already at micromolar concentrations of sulforaphane and that this sulforaphane -mediated induction of cellular defenses is accompanied by a marked increase in resistance to ROS-induced cardiac cell injury."

Potent Induction of Total Cellular and Mitochondrial Antioxidants and Phase 2 Enzymes by Cruciferous Sulforaphane in Rat Aortic Smooth Muscle Cells: Cytoprotection Against Oxidative and Electrophilic Stress
Zhu et al. Cardiovasc Toxicol. 2008 Fall;8(3):115-25
(doi: 10.1007/s12012-008-9020-4)

Dosage = 0.5, 1, 2.5, and 5 uM SFN for 48 h

- "This study demonstrates that in the aortic smooth muscle cells sulforaphane at physiologically relevant concentrations potently induces a series of total cellular as well as mitochondrial antioxidants and phase 2 enzymes, which is accompanied by dramatically increased resistance of these vascular cells to oxidative and electrophilic stress"

Sulforaphane effects on oxidative stress parameters in culture of adult cardiomyocytes
Corsacc et al. Biomed Pharmacother. 2018 Aug;104:165-171
(doi: 10.1016/j.biopha.2018.05.031)

Dosage = 5 uM SFN for 1 or 24 h

- "Based on these results, it is possible to observe that sulforaphane had a protective action against damage and increased ROS levels."

Cruciferous Vegetable Phytochemical Sulforaphane Affects Phase II Enzyme Expression and Activity in Rat Cardiomyocytes through Modulation of Akt Signaling Pathway
Leoncini et al. J Food Sci. 2011 Sep;76(7):H175-81
(doi: 10.1111/j.1750-3841.2011.02311.x)

Dosage = 5 uM SFN for 0.5, 12 or 24 h

- "This study yielded the major finding that the PI3K/Akt pathway represents a central molecular mechanism through which sulforaphane exerts its biomodulatory effect on phase II enzymes. Data here reported demonstrate that this mechanism is linked to a general cytoprotective action against oxidative damage generated in neonatal rat cardiac myocytes by 100 μMH2O2 exposure."

17β-Estradiol enhances sulforaphane cardioprotection against oxidative stress
Angeloni et al. J Nutr Biochem. 2017 Apr;42:26-36
(doi: 10.1016/j.jnutbio.2016.12.017)

Dosage = 0.1 to 0.5 uM SFN for 24h

- “In agreement with biochemical data, only cardiomyocytes pretreated with sulforaphane in the presence of E2 showed a well-preserved morphology comparable with control cells; meanwhile, sulforaphane or E2 alone was able to preserve, only partially, cell morphology impaired by H2O2 exposure.”

4. Greater muscle growth

Initial studies have found that glucoraphanin/sulforaphane act to suppress the production of myostatin and induce the production of myogenin in muscle cells. Myostatin is a muscular protein which acts to limit muscle growth while myogenin drives muscle growth - indicating that glucoraphanin/sulforaphane supplements could help boost muscle growth.

Sulforaphane prevents age-associated cardiac and muscular dysfunction through Nrf2 signaling

Bose et al. Aging Cell. 2020 Nov;19(11):e13261
(doi: 10.1111/acel.13261. Epub 2020 Oct 17)

Dosage = Diet supplemented with 442.5 mg/kg SFN for 12 weeks (mice had free access to food)

- "Sulforaphane (sulforaphane) improves grip strength, exercise performance, and numbers of skeletal muscle stem cells in the mouse."
- "The proportions of the Pax7- (Figure 2c) and MyoD (Figure 2d)-positive satellite cell progeny in both young and old mice on sulforaphane diet were significantly higher than in their age-matched controls. sulforaphane treatment may increase new satellite cell formation to meet the routine needs of muscle homeostasis, or potentially the more sporadic demands for hypertrophy or repair."
- " The sulforaphane fed old mice performed similarly to young animals"
- "Nrf2 activity was upregulated in the nuclear extracts of both hearts and SKM (gastrocnemius lateralis) of sulforaphane-fed young and old mice compared to their age-matched controls"

Sulforaphane protects against skeletal muscle dysfunction in spontaneous type 2 diabetic db/db mice

Wang et al. Life Sci. 2020 Aug 15;255:117823
(doi: 10.1016/j.lfs.2020.117823. Epub 2020 May 20)

Dosage = 0.5 mg/kg SFN daily via intraperitoneal injection for one month

- "We found that sulforaphane could significantly increase the grip strength of the db/db mice."
- "The lean mass and gastrocnemius mass were increased in the db/db mice after administration with sulforaphane."

Sulforaphane mitigates muscle fibrosis in mdx mice via Nrf2-mediated inhibition of TGF-β/Smad signaling
Sun et al. J Appl Physiol (1985). 2016 Feb 15;120(4):377-90
(doi: 10.1152/japplphysiol.00721.2015)

Dosage = 2 mg/kg SFN via daily gavage for 3 months

- "We first examined skeletal and cardiac muscle mass and found that sulforaphane treatment enhanced the skeletal mass of TA, TB, SOL, EDL, and QUAD muscles, which indicated that sulforaphane promotes muscle regeneration of skeletal muscles."
    - [Tibial anterior (TA), triceps brachii (TB), extensor digitorum longus (EDL), soleus (SOL), and quadriceps (QUAD) muscles]

Sulforaphane reduces lipopolysaccharide-induced inflammation and enhances myogenic differentiation of mouse embryonic myoblasts via the toll-like receptor 4 and NLRP3 pathways
Wang et al. Adv Clin Exp Med. 2023 Apr;32(4):457-467
(doi: 10.17219/acem/155342)

Dosage = 1 to 30 uM SFN for 6, 24, 72 or 120 h

- "Sulforaphane treatment significantly increased gene and protein expression of myoD and myogenin"
- "Mechanistically, sulforaphane reduced messenger ribonucleic acid and protein levels of TLR4, NLRP3, apoptosis-associated speck-like protein, and Caspase-1 in C2C12 cells, thereby inhibiting the inflammatory response and promoting myogenic differentiation."

Sulforaphane Enhanced Proliferation of Porcine Satellite Cells via Epigenetic Augmentation of SMAD7
Zhang et al. Animals (Basel). 2022 May 26;12(11):1365
(doi: 10.3390/ani12111365)

Dosage = 5, 10, 15 or 20 uM SFN for 1 or 2 days

- "Satellite cells are essential for muscle development, maintenance, and regeneration since they are the skeletal muscle's stem cells. sulforaphane dramatically boosted PSC proliferation and SMAD7 mRNA and protein expression."
- "Our work indicates that sulforaphane supplementation in the diet can help with muscle growth and repair through satellite cell proliferation enhancement."

Sulforaphane prevents dexamethasone-induced muscle atrophy via regulation of the Akt/Foxo1 axis in C2C12 myotubes

Son et al. Biomed Pharmacother. 2017 Nov;95:1486-1492
(doi: 10.1016/j.biopha.2017.09.002)

Dosage = 1, 5 or 10 uM SFN for 24 h

- "Sulforaphane (at 1 or 5 μM) reduced myostatin mRNA levels but increased myogenin mRNA levels."
- "Co-treatment with sulforaphane and DEX showed that sulforaphane reduced myostatin and Atrogin-1 up-regulations caused by DEX and recovered MyoD mRNA."

Sulforaphane causes a major epigenetic repression of myostatin in porcine satellite cells

Fan et al. Epigenetics. 2012 Dec 1;7(12):1379-90
(doi: 10.4161/epi.22609. Epub 2012 Oct 23)

Dosage = 5, 10, and 15 uM SFN for 48 h

- "Sulforaphane and 5-aza-dC treatments clearly result in attenuated MSTN expression" (in porcine satellite cells)
- (Myostatin (MSTN) is a potent inhibitor of skeletal muscle growth.9 MSTN can also block satellite cell activation and negatively regulate self-renewal of satellite cells)

5. Reduced body fat

Various studies have indicated that glucoraphanin/sulforaphane can drive changes in metabolism, which can help to reduce body fat levels through a variety of mechanisms (including reversing leptin resistance, converting inert 'white fat' to active 'brown fat' that burns energy[1], and altering the composition of the microbiome to a more favourable profile).

Sulforaphane ameliorates lipid profile in rodents: an updated systematic review and meta-analysis
Du et al. Sci Rep. 2021 Apr 8;11(1):7804
(doi: 10.1038/s41598-021-87367-9)

Dosage = Variable, most studies included featured from 0.5 mg up to 30 mg/kg of body weight per day via oral gavage or intraperitoneal or subcutaneous injection for between 3 and 16 weeks (one study used 1g/kg of diet)

- "Sulforaphane reduced body weight (WMD: − 2.76 g, 95% CI: − 4.19, − 1.34) and liver weight (WMD: − 0.93 g, 95% CI: − 1.63, − 0.23) significantly in our ten trials."
- "This is the first meta-analytic study that summarizes the function of sulforaphane mono-treatment on lipid profile in rodents with metabolic syndrome."

The Effects of Aerobic-Resistance Training and Broccoli Supplementation on Plasma Dectin-1 and Insulin Resistance in Males with Type 2 Diabetes
Saeidi et al. Nutrients. 2021 Sep 9;13(9):3144
(doi: 10.3390/nu13093144)

Dosage = 10g broccoli supplement per day for 12 weeks (approximately 225 umol SFN, or 22.5 mmol/g)

- Human RCT, N=44 T2D patients. Supplement of 225 umol SFN /day for 12 weeks
- "We report greater weight loss (Training+Supplement—12%, Training+Placebo—7%), with our exercise program causing a higher stimulation and greater improvements in lipid profiles."

Sulforaphane reduces obesity by reversing leptin resistance
Cakir et al. Elife. 2022 Mar 24;11:e67368
(doi: 10.7554/eLife.67368)

Dosage = 5 mg/kg SFN via daily intraperitoneal injection for 4 weeks

- "We observed that sulforaphane suppressed food intake in wild-type diet-induced obese mice"
- "Sulforaphane treatment did not decrease the food intake of lean mice"
- "The antiobesity effect of sulforaphane requires functional leptin receptor signaling"
- "Our results suggest the skeletal muscle as the most notable site of action of sulforaphane whose peripheral NRF2 action signals to alleviate leptin resistance"

Broccoli microgreens juice reduces body weight by enhancing insulin sensitivity and modulating gut microbiota in high-fat diet-induced C57BL/6J obese mice
Li et al. Eur J Nutr. 2021 Oct;60(7):3829-3839
(doi: 10.1007/s00394-021-02553-9)

Dosage = 0.4ml 20 mg/kg bw broccoli microgreen juice via daily oral gavage for 8 weeks

- "BMJ supplementation could reduce WAT mass and body weight of mice, and increase water intake, and reduce adipose cell size. Repaired liver tissues by BMJ intervention were associated with improving liver antioxidant ability. Moreover, the protective effects of BMJ on diet-induced obesity may be involved in gut microbiota–SCFAs–LPS–inflammatory axis. Furthermore, BMJ significantly enhanced insulin sensitivity and improved dyslipidemia."

Glucoraphanin Ameliorates Obesity and Insulin Resistance Through Adipose Tissue Browning and Reduction of Metabolic Endotoxemia in Mice
Nagata et al. Diabetes. 2017 May;66(5):1222-1236
(doi: 10.2337/db16-0662)

Dosage = High fat diet containing 0.3% GR (containing 2.2% extract powder) for 14 weeks. Extract powder contained 135 mg GR/g or 0.31 mmol GR/g. Mice had free access to food

- "Glucoraphanin supplementation attenuated weight gain, decreased hepatic steatosis, and improved glucose tolerance and insulin sensitivity in HFD-fed wild-type mice but not in HFD-fed Nrf2-knockout mice."
- "Compared with vehicle-treated controls, glucoraphanin-treated HFD-fed mice had lower plasma lipopolysaccharide levels and decreased relative abundance of the Gram-negative bacterial family Desulfovibrionaceae in their gut microbiomes."
    - "Recent studies demonstrated that a significant increase in Desulfovibrionaceae, potential endotoxin producers, in the gut microbiomes of both HFD-induced obese mice and obese human subjects compared to lean individuals"

Sulforaphane Regulates Glucose and Lipid Metabolisms in Obese Mice by Restraining JNK and Activating Insulin and FGF21 Signal Pathways
Tian et al. J Agric Food Chem. 2021 Nov 10;69(44):13066-13079
(doi: 10.1021/acs.jafc.1c04933)

Dosage = 10 mg/kg SFN via daily oral gavage for 8 weeks

- "Sulforaphane and metformin appeared to exert equivalent effects in terms of decreasing the fat/body ratio in obese mice."
- "Sulforaphane was indeed found to improve aspects of metabolic syndromes, such as insulin resistance, NAFLD, inflammation, adipose tissue hypertrophy, and oxidative stress."
- "These beneficial effects of sulforaphane were regulated by decreasing liver gluconeogenesis and lipid accumulation, increasing glucose transport, and promoting liver glycogen synthesis, as well as by improving FGF21 resistance."
- "We found that sulforaphane could improve glucose and lipid metabolism via the restraint of JNK and the activation of insulin and the FGF21 signaling pathway"
- "Our research provides an empirical basis for clinical treatment with sulforaphane in obesity"

Targeting PLIN2/PLIN5-PPARγ: Sulforaphane Disturbs the Maturation of Lipid Droplets

Tian et al. Mol Nutr Food Res. 2019 Oct;63(20):e1900183
(doi: 10.1002/mnfr.201900183)

Dosage = 5, 10 and 20 mg/kg SFN by oral gavage three times a week for 10 weeks

- "It is demonstrated that sulforaphane decreases TG and CE, which are key elements of the neutral lipid core of LDs, by inactivating enzymes key to their synthesis"
- "Intriguingly, this is to our knowledge the first report that sulforaphane can downregulate PLIN2 and PLIN5—two members of PAT family protein that coat the surface of LDs."
- "The numbers and sizes of LDs are decreased by sulforaphane"

Sulforaphane Improves Lipid Metabolism by Enhancing Mitochondrial Function and Biogenesis In Vivo and In Vitro

Lei et al. Mol Nutr Food Res. 2019 Feb;63(4):e1800795
(doi: 10.1002/mnfr.201800795)

Dosage = 1, 5 and 10 uM SFN for 24 or 48h

- "Interestingly, we observed the induction of lipolysis in sulforaphane-treated cells"
- "Sulforaphane improves mitochondrial function and elevate mitochondrial biogenesis, reducing lipid content in vivo and in vitro."

Sulforaphane improves leptin responsiveness in high-fat high-sucrose diet-fed obese mice

Shawky et al. Eur J Pharmacol. 2018 Sep 15;835:108-114
(doi: 10.1016/j.ejphar.2018.07.050)

Dosage = 0.5 mg/kg SFN daily via subcutaneous injection for 23 days

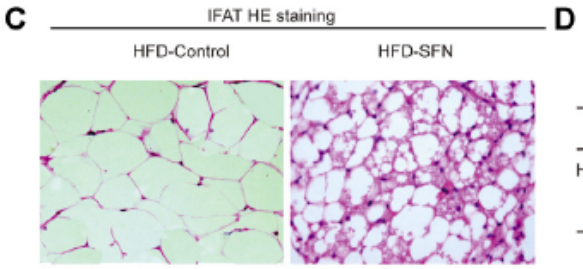
- "in HFHS diet-fed obese mice, sulforaphane treatment (0.5 mg/kg/day, s.c.) for ~2–3 weeks improves the responsiveness to exogenously administered leptin as revealed by temporal decreases in food intake and weight gain."

The Protective Effects of Sulforaphane on High-Fat Diet-Induced Obesity in Mice Through Browning of White Fat

Liu et al. Front Pharmacol. 2021 Apr 29;12:665894
(doi: 10.3389/fphar.2021.665894)

Dosage = 10 mg/kg SFN daily via intraperitoneal injection for 30 days

- "Sulforaphane treatment substantially decreased the adipocyte size and body weight gain, and further prevented HFD-induced obesity through the browning of adipocytes via mitochondrial biogenesis and the activation of Ucp1 and Pgc1-α."
- "Sulforaphane reduced the lipid droplets and the size of adipose cell from IWAT and VWAT." (below)



Group	Average Cell size (μm²)	P value
HFD-Control	8802.5 ± 2899.1	*P* =0.0003
HFD-SFN	3543 ± 1640.1	

Beneficial Effects of Broccoli (Brassica oleracea var italica) By-products in Diet-induced Obese Mice

Martins et al. In Vivo. 2022 Sep-Oct;36(5):2173-2185
(doi: 10.21873/invivo.12943)

Dosage = *ad libitum diet with 0.67% w/w or 1.34% w/w broccoli flour for 4 weeks or 14 weeks*

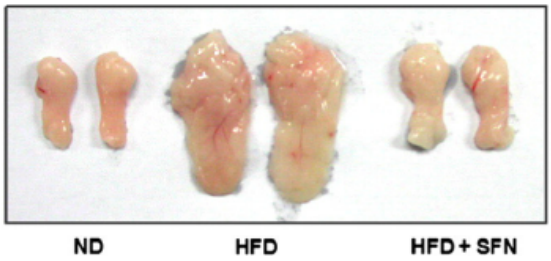
- "In the present study, the increase in adipocyte volume observed in the WD group was reversed by BF supplementation."

Sulforaphane attenuates obesity by inhibiting adipogenesis and activating the AMPK pathway in obese mice

Choi et al. J Nutr Biochem. 2014 Feb;25(2):201-7
(doi: 10.1016/j.jnutbio.2013.10.007. Epub 2013 Nov 14)

Dosage = 1g SFN/kg of food for 6 weeks. Mice had free access to food

- "In this study, sulforaphane markedly reduced the body weight of HFD-induced obese mice, and HFD plus sulforaphane-fed mice showed a similar pattern of weight gain to the ND-fed group"
- "We found that sulforaphane strongly decreased the expression of PPARγ and C/EBPα in epididymal adipose tissue."
- "Effect of sulforaphane on adipose tissues and liver in HFD-induced obese mice. (B) epididymal adipose tissue (below)"



Anti-Obesogenic Effects of Sulforaphane-Rich Broccoli (Brassica oleracea var. italica) Sprouts and Myrosinase-Rich Mustard (Sinapis alba L.) Seeds In Vitro and In Vivo

Men et al. Nutrients. 2022 Sep 15;14(18):3814
(doi: 10.3390/nu14183814)

Dosage = 150 mg/kg per day oral broccoli sprout powder (containing 131.11 umol/g GR) for 12 weeks

- "These results suggest that MBP and BSP (broccoli sprout powder) treatment improves serum HDL-c and TG levels in C57BL/6J mice with BPA-induced obesity."
- "Taken together, these data clearly demonstrate that BSP and MBP are effective in preventing BPA-induced obesity by controlling adipogenesis, lipogenesis, and fatty acid oxidation."

Sulforaphane induces lipophagy through the activation of AMPK-mTOR-ULK1 pathway signalling in adipocytes

Masuda et al. J Nutr Biochem. 2022 Aug;106:109017
(doi: 10.1016/j.jnutbio.2022.109017. Epub 2022 Apr 21)

Dosage = in vitro cells treated with 10 or 100 uM SFN for 3h or 10 days; mice were administered 30 mg/kg SFN once before sacrifice via intraperitoneal injection

- "Sulforaphane was shown to induce lipophagy through the AMPK-mTOR-ULK1 signalling pathway in adipocytes, resulting in the reduction of lipid droplets."

Effects of long-term consumption of broccoli sprouts on inflammatory markers in overweight subjects

Lopez-Chillon et al. Clin Nutr. 2019 Apr;38(2):745-752
(doi: 10.1016/j.clnu.2018.03.006. Epub 2018 Mar 13)

Dosage = 30g of broccoli sprouts daily for 70 days (roughly 51 mg or 117 umol GR)

- "In our study we observed a noticeable anti-inflammatory effect with the ingestion of broccoli sprouts, with a significant reduction by 38% and 59% in IL-6 and C-reactive protein concentrations, respectively."

Modulation of Adipocyte Differentiation and Proadipogenic Gene Expression by Sulforaphane, Genistein, and Docosahexaenoic Acid as a First Step to Counteract Obesity

Valli et al. Oxid Med Cell Longev. 2018 Feb 7;2018:1617202
(doi: 10.1155/2018/1617202. eCollection 2018)

Dosage = 10, 25, 50 uM SFN for 4 days

- "All bioactive compounds markedly reduced lipid droplet formation compared to controls. GEN and sulforaphane were effective at the lowest concentration used for supplementation (10 μM)"

6. Improved cardiovascular function

There is a growing body of research indicating that glucoraphanin/sulforaphane can help support the heart health and the health of our cardiovascular system (for example, by reducing LDL cholesterol (LDL) levels and the risk of cardiac health events), which offers promise for athletes looking to keep their heart and circulation in peak condition.

Sulforaphane prevents age-associated cardiac and muscular dysfunction through Nrf2 signaling

Bose et al. Aging Cell. 2020 Nov;19(11):e13261
(doi: 10.1111/acel.13261)

Dosage = Diet supplemented with 442.5 mg/kg SFN for 12 weeks (mice had free access to food)

- "Sulforaphane supplementation improved the ejection fraction (76.0 ± 1.4), fractional shortening (44.2 ± 1.3%), and the stroke volume (51.6 ± 11.3 µl) in the old mice."
- "Cardiac output in sulforaphane-fed old mice was similar to that of young controls."
- "We conclude that sulforaphane-fed old mice developed resistance to age associated loss of cardiac function."

Broccoli Sprouts Promote Sex-Dependent Cardiometabolic Health and Longevity in Long-Evans Rats

Noble et al. Int J Environ Res Public Health. 2022 Oct 18;19(20):13468
(doi: 10.3390/ijerph192013468)

Dosage = 300 mg/kg air dried broccoli sprouts 3 times a week from 4 months of age till death (about 18 months)

- "Glucoraphanin-fed females had a lower body weight and visceral adiposity while Glucoraphanin-fed males exhibited improved glucose tolerance and reduced blood pressure when compared to their control counterparts"

Dietary approach to attenuate oxidative stress, hypertension, and inflammation in the cardiovascular system
Wu et al. Proc Natl Acad Sci U S A. 2004 May 4;101(18):7094-9
(doi: 10.1073/pnas.0402004101)

Dosage = 200 mg air-dried broccoli sprouts (containing approx. 12 umol of GR per gram) fed daily for 14 weeks

- "Decreased oxidative stress correlated with better endothelial-dependent relaxation of the aorta and significantly lower (20 mm Hg) blood pressure." [in sulforaphane group]

Diet rich in high glucoraphanin broccoli reduces plasma LDL cholesterol: Evidence from randomised controlled trials
Armah et al. Mol Nutr Food Res. 2015 May;59(5):918-26
(doi: 10.1002/mnfr.201400863)

Dosage = 400 g standard broccoli (6.9 umol/g GR) or 400 g high GR broccoli (21.6 umol/g GR) per week for 12 weeks

- "Volunteers consuming the high-glucoraphanin broccoli had significant reduction in plasma LDL-C compared to their own baseline level"

Fruit and vegetable intake in relation to risk of ischemic stroke
Joshipura et al. JAMA. 1999 Oct 6;282(13):1233-9
(doi: 10.1001/jama.282.13.1233)

Dosage = Vegetable intake measured as servings per day (highest quintile intake was 6.2 servings per day for women and 5.4 for mean; lowest quintile intake was 1.6 for women and 1.4 for men)

- "These data support a protective relationship between consumption of fruits and vegetables – particularly cruciferous and green leafy vegetables and citrus fruit and juice – and ischemic stroke risk."

7. Improved joint health

There is a growing body of research indicating that glucoraphanin/sulforaphane can help support joint health (for example, by reducing inflammation in joint spaces, which is a common driver of many forms of arthritis). This offers promise for athletes, who put additional strain on their joints through intense exercise that can lead to injury and long-term damage to joints, including an increased risk of developing arthritis.

Isothiocyanates are detected in human synovial fluid following broccoli consumption and can affect the tissues of the knee joint
Davidson et al. Sci Rep. 2017 Jun 13;7(1):3398
(doi: 10.1038/s41598-017-03629-5)

Dosage = 100 g high GR broccoli (1.8 umol/g GR) per day for 14 days

- "This is the first human study to show that increased broccoli intake results in ITC uptake into the joint, with concomitant changes in the joint."

High bone mass in mice can be linked to lower osteoclast formation, resorptive capacity, and restricted in vitro sensitivity to inhibition by stable sulforaphane
Louka et al. Cell Biochem Funct. 2022 Oct;40(7):683-693
(doi: 10.1002/cbf.3734)

Dosage = SFN (sulforadex, SFX-01), 100 nm to 2.5 uM SFX-01 for 5 days

- "Further studies using STR/ORT cells, found that 2.5 μM SFX‐01 was sufficient to reduce both osteoclast number and their total resorptive capacity"

Sulforaphane Represses Matrix-Degrading Proteases and Protects Cartilage From Destruction In Vitro and In Vivo

Davidson et al. Arthritis Rheum. 2013 Dec;65(12):3130-40
(doi: 10.1002/art.38133)

Dosage = in vitro cells treated with 2.5 uM to 30 uM SFN for 30 mins or 2 hrs; mice receive a diet containing 0.18 or 0.6 g/kg SFN ad libitum for 4 weeks (0.6 g/kg SFN equates to 3 umols SFN/day)

- "Sulforaphane inhibits the expression of key metalloproteinases implicated in osteoarthritis, independently of Nrf2, and blocks inflammation at the level of NF-kB to protect against cartilage destruction in vitro and in vivo."

Anabolic and Antiresorptive Modulation of Bone Homeostasis by the Epigenetic Modulator Sulforaphane, a Naturally Occurring Isothiocyanate

Thaler et al. J Biol Chem. 2016 Mar 25;291(13):6754-71
(doi: 10.1074/jbc.M115.678235. Epub 2016 Jan 12)

Dosage = in vitro cells treated with 3 uM L or DL-SFN for 16h, 24h, or 12 days; 7.5mM DL-SFN (12.76 mg/kg) via intraperitoneal injection every other day for 5 weeks

- "Here we show that sulforaphane (sulforaphane), a naturally occurring isothiocyanate, promotes osteoblast differentiation by epigenetic mechanisms."
- "Sulforaphane decreases the expression of the osteoclast activator receptor activator of nuclear factor- B ligand (RANKL) in osteocytes and mouse calvarial explants and preferentially induces apoptosis in preosteoclastic cells via up-regulation of the Tet1/Fas/Caspase 8 and Caspase 3/7 pathway."
- "These mechanistic effects correlate with higher bone volume (20%) in both normal and ovariectomized mice treated with sulforaphane for 5 weeks compared with untreated mice as determined by microcomputed tomography."