Non-alcoholic Fraction of Beer

Subjects: Nursing
Contributor: Rosa Lamuela-Raventos

The present review focuses on the effects of non-alcoholic components of beer on abdominal fat, osteoporosis and body hydration in women, conditions selected for their relevance to health and aging. Although beer drinking is commonly believed to cause abdominal fat deposition, the available literature indicates this outcome is inconsistent in women. Additionally, the non-alcoholic beer fraction might improve bone health in postmenopausal women, and the effects of beer on body hydration, although still unconfirmed seem promising. Most of the health benefits of beer are due to its bioactive compounds, mainly polyphenols, which are the most studied. As alcohol-free beer also contains these compounds, it may well offer a healthy alternative to beer consumers.

Keywords: phytoestrogen ; hops ; menopause

Several studies have shown that binge drinking of alcoholic beverages leads to non-desirable outcomes, which have become a serious threat to public health. However, the bioactive compounds in some alcohol-containing beverages might mitigate the negative effects of alcohol. In beer, the variety and concentration of bioactive compounds in the non-alcoholic fraction suggests that its consumption at moderate levels may not only be harmless but could also positively contribute to an improvement of certain physiological states and be also useful in the prevention of different chronic diseases.

1. Introduction

Beer, an alcoholic drink composed of four main ingredients (water, malt, hops, and yeast) [1], is one of the most consumed beverages in the world [2]. From a nutritional point of view, its main components are water (around 90%), followed by carbohydrates, ethanol, minerals, vitamins, and bioactive compounds such as polyphenols and organic acids (iso-α-humulones). Beer composition, as well as its flavor, taste, and texture, differs considerably according to the ingredients and processing techniques [3]. Besides their health benefits, the bioactive compounds are also linked to the sensory characteristics of beer [4].

2. Beer Consumption Related to Health and Disease in Women

2.1. Beer, Abdominal Fat, and Weight Gain

A widely held belief is that beer consumption directly contributes to an increase in abdominal fat and ultimately leads to overweight and obesity. This assumption might be due to the nutritional value of beer, since it contains not only alcohol but also more carbohydrates than other alcoholic drinks [5]. In this section, we assess whether or not beer consumption can increase abdominal fat and site-specific adiposity in women, central obesity being the most relevant sign of metabolic syndrome (MetS) [6].

Several studies have investigated the effects of gender in the relationship between beer consumption and abdominal adiposity [5][7]. A systematic review of observational studies published before November 2010 indicates that there is an inverse or no association between general obesity and moderate beer consumption in women, while findings referring to abdominal obesity seem to be inconsistent [7]. The authors pointed out that these conflicting observational data may be explained by the small proportion of women beer drinkers and their relatively low beer intake in the studies analyzed [7].

Alcohol or beer consumption and abdominal fat or weight gain have been described as having a U-shaped relationship, with the lowest BMI values observed in women who consumed an average of 6–24 g/day of alcohol [8]. In another study, women with a low beer consumption (maximum 1.32 L/week) also had the lowest WHR values, whereas non-consumers had the highest WC [9]. In the Third National Health and Nutrition Examination Survey (NHANES III), the lowest MetS and WC values were observed in the mild to moderate beer and wine drinkers [10]. Consequently, it can be stated that excessive beer intake may contribute to a higher WC and WHR, and even a higher overall BMI, yet the regular consumption of less than 0.5 L/day of beer (4% alcohol) seems unlikely to have this effect, according to the data available in cross-sectional and prospective observational studies [7].

In a study focused on the effects of a moderate beer intake on the body composition of healthy adults undergoing a high-intensity interval training, the group consuming alcohol-free beer experienced a significant decrease in visceral adipose tissue and WC, and a clear decreasing trend in the WHR. The other groups (consuming beer or water supplemented with vodka ethanol) did not show any changes in these variables [11].

Now, we should look for the compounds of regular and non-alcoholic beer responsible of these effects. The main bitter compounds of beer are iso-α-acids or iso-α-humulones, derived from the isomerization of α-acids in hops during brewing [12][13]. A study of mice fed with a high-fat diet (HFD) supplemented with iso-α-acids reported significantly reduced body weight, epididymal fat weight, and plasma triglyceride levels after the intervention, whereas in the control group the values increased [14]. As in other studies, it was concluded that iso-humulones might have a protective effect on internal organs damaged by obesity, making this a promising line of future research [14][15]. Iso-α-acids bind and activate both peroxisome proliferator-activated receptors α (PPARα) and γ (PPARγ), which exhibit anti-obesity and anti-inflammatory activities in vivo [14][15][16]. Regular beers contain 20–40 mg/L of iso-α-acids [17][18][19], and some bitter beers up to 50–80 mg/L [18].

2.2. Beer and Osteoporosis

Known as one of the most important health-related conditions of aging, osteoporosis is attributed to a decrease of bone mineral density (BMD), which ultimately leads to increased bone fragility [20]. Although common, the condition is underdiagnosed and undertreated, and clinical trials and public health strategies are needed to improve screening and management [21]. Nutrition, exercise and lifestyle are recognized as important aspects in osteoporosis prognosis [22], so modifiable environmental factors such as diet should be considered in its management [23].

Most of the positive effects of beer on osteoporosis in postmenopausal women have been attributed to the non-alcoholic fraction, specifically to polyphenols, silicon and α-acids. Among phenolic compounds, flavonoids have been inversely linked to bone resorption biomarkers in Scottish women aged 45–54 years. The flavonoids most consumed by the participants were catechins, demonstrating the significant contribution of these compounds to improving BMD [24][25]. The bioactive compounds in hops have been proposed as an alternative to conventional hormone replacement therapy. In particular, the phenolic phytoestrogens from hop extract seem to exhibit estrogen-like effects on bone metabolism [26]. A recent study in animals found that hop extract containing phytoestrogens and iso-α-acids attenuated bone loss and reversed high bone turnover in ovariectomy mice [27]. Furthermore, in vitro experiments demonstrate that hop phytoestrogens (XN, IX, 6-PN, and 8-PN) regulate both osteoblast and osteoclast activities, while α-acids exert a strong bone resorption inhibitory activity, however, the recommended dosage is still unclear [26][27][28].

The phytoestrogen XN inhibits the receptor activator for the nuclear factor κ B ligand (RANKL) signaling pathway, which has been identified as critical to osteoclast formation and bone resorption [29][30]. XN has also been reported to promote osteoblast differentiation, up-regulate alkaline phosphatase activity, and increase the expression of osteogenic marker genes in osteoblastic cell lines [31]. Interestingly, Prouillet et al. (2004) had previously suggested that one of the consequences of increased alkaline phosphatase activity could be an activation of the ER [30], and another study described an inhibitory resorption effect of XN in a dose-dependent manner [28]. Regarding 8-PN, a recent review of its therapeutic perspectives discusses plausible mechanisms for the anti-osteoporotic properties of this intestinal metabolite. 8-PN has preferential binding to ER-α, which is the prevailing ER in bone tissue, and its prenyl group seems to be essential for the anti-osteoporotic mechanism [32]. In summary, the beneficial effects of 8-PN, promoting bone formation and inhibiting bone resorption, are mediated by ER-α instead of ER-β, and it is more potent than the isoflavones genistein and daidzein [33].

To sum up, bone remodeling is a slow process and aging affects bone turnover [34]. The phenolic fraction of beer, including phytoestrogens and iso-α-acids from hops, and the silicon from malt seem to play a role in osteoporosis prevention. However, long-term clinical trials are needed to better predict the impact of beer consumption on bone mass, a major concern for postmenopausal women suffering from bone loss.

2.3. Beer and Body Hydration

Hydration has a crucial impact on a variety of factors related to the correct functioning of the body and specific recommendations are needed for each population group. Female sex hormones affect the body water balance, although it is still unclear how the regulation of hydration in women may enhance wellness, safety, and mental and physical performance [35]. Estrogen and progesterone levels have been correlated with body fluid regulation and thermoregulation changes [35]. As more water is retained in the body when estrogen levels are high [36], hormonal depletion in menopause results in a loss of hydration, which should be carefully monitored. Current literature reports that estrogen therapy increases osmotic sensitivity and water retention, helping menopausal women to control diuresis and prevent dehydration [37]. The effect of estrogen on fluid regulation in older women seems to be related to sodium retention [36][38]. Not only the menopause but aging itself affects the fluid balance [37].

Several studies have investigated the effect of beer or its components in those practicing sports, monitoring hydration status, muscle performance, environmental conditions, and duration of exercise in male athletes [39][40][41]. The most controversial component of beer is ethanol. An early study from 1997 reported that the retention volume of the total fluid ingested was about 20% lower in those who consumed an alcohol-free beer supplemented with 4% alcohol compared to those who drank non-supplemented alcohol-free beer, following intermittent cycle ergometer exercises in the heat that induced dehydration of up to 2% of body mass [42]. Alcohol itself undoubtedly has a negative effect on exercise performance, although its extent may also depend on other factors, such as the mode and duration of exercise [40]. In extreme conditions, when the body requires greater hydration, any diuretic or anti-hydration effect of the ethanol in beer is more easily noted. Jiménez-Pavón et al. (2015) observed that consumption of 660 mL of regular beer (4% alcohol) after 1 h of running in hot conditions had no deleterious effect on any hydration marker [43]. Two other studies evaluated the effect of water, beer or alcohol-free beer on fluid and electrolyte homeostasis in male athletes or physically active men [44][45]. Castro-Sepulveda et al. (2016) reported that an intake of 700 mL of alcoholic beer before aerobic exercising increased plasma K^+ and decreased plasma Na^+ during the exercise activity, with a negative impact on athletic performance. Notably, this effect was not observed when alcohol-free beer was administered, to the extent that the decrease in plasma Na^+ during exercise was lower than after the ingestion of water. Accordingly, alcohol-free beer might be an effective sports drink for maintaining electrolyte homeostasis in males when taken before exercise [45]. In contrast, another study found that rehydration of young, healthy, and physically active males with non-alcoholic beer was not advantageous with regard to water [44]. A more recent study evaluated the effects of ingesting isotonic drinks or beer with different alcohol concentrations after mild dehydration or exercise among males. The net fluid balance was measured after a 5-hour observation period and the lowest rate of fluid retention (21%) was obtained for beer with 5% alcohol, whereas the highest (42%) was recorded for an isotonic sports drink [46]. Interestingly, the effects of modifying the sodium and alcohol content of beer have also been studied [47][48]. Participants consumed low-alcohol beer (2% alcohol + 25 or 50 mM/L of sodium) or normal beer (3.5% alcohol + 25 mM/L of sodium) and after exercise, the greatest fluid retention was observed in consumers of beer with the highest electrolyte content and the lowest concentration of alcohol (2% alcohol + 50 mM/L of sodium) [48].

While non-alcoholic beer has promising effects in terms of fluid homeostasis in the context of aerobic exercise, a low dose of alcohol (0.5 g/kg of body weight) consumed before muscle damage-inducing anaerobic exercise had no impact on the posterior muscle performance or related water loss in ten healthy young males [41].

Notably, all the aforementioned studies were performed in men. More research is needed to understand the effects of different types of drinks on the hydration state of female athletes, in order to improve performance and provide personalized supplementation recommendations [35].

References

1. Buiatti, S. Beer Composition: An Overview. In Beer in Health and Disease Prevention; Elsevier: London, UK, 2009; pp. 213–225. ISBN 9780123738912.
2. Colen, L.; Swinnen, J. Economic growth, globalisation and beer consumption. J. Agric. Econ. 2016, 67, 186–207.
3. Handbook of Brewing, 2nd ed.; Stewart, G.G.; Priest, F.G. (Eds.) CRC Press: Boca Raton, FL, USA, 2006; ISBN 9780429116179.
4. Tucker, K.L.; Jugdaohsingh, R.; Powell, J.J.; Qiao, N.; Hannan, M.T.; Sripanyakorn, S.; Cupples, L.A.; Kiel, D.P. Effects of beer, wine, and liquor intakes on bone mineral density in older men and women. Am. J. Clin. Nutr. 2009, 89, 1188–

1196.

5. Wannamethee, S.G. Beer and Adiposity; Elsevier Inc.: Amsterdam, The Netherlands, 2009; ISBN 9780123738912.
6. Zugravu, C.-A.; Pătrașcu, D.; Otelea, M. Central obesity and beer consumption. Ann. Univ. Dunarea Jos Galati Fascicle VI Food Technol. 2019, 43, 110–124.
7. Nathalie T Bendsen; Robin Christensen; Else M Bartels; Frans J Kok; Aafje Sierksma; Anne Raben; Arne Astrup; Is beer consumption related to measures of abdominal and general obesity? A systematic review and meta-analysis. *Nutrition Reviews* **2012**, *71*, 67-87, 10.1111/j.1753-4887.2012.00548.x.
8. Manuela M Bergmann; M Schütze; A. Steffen; H Boeing; J Halkjaer; Anne Tjønneland; Noémie Travier; Antonio Agudo; N Slimani; Sabina Rinaldi; et al. The association of lifetime alcohol use with measures of abdominal and general adiposity in a large-scale European cohort. *European Journal of Clinical Nutrition* **2011**, *65*, 1079-1087, 10.1038/ejcn.2011.70.
9. Corina-Aurelia Zugravu; Daniela Pătrașcu; Mariana Otelea; Central obesity and beer consumption. *The Annals of the University Dunarea de Jos of Galati Fascicle VI – Food Technology* **2019**, *43*, 110-124, 10.35219/foodtechnology.2019.2.08.
10. Matthew S. Freiberg; Howard J. Cabral; Tim C. Heeren; Ramachandran S. Vasan; R. Curtis Ellison; Alcohol Consumption and the Prevalence of the Metabolic Syndrome in the U.S.: A cross-sectional analysis of data from the Third National Health and Nutrition Examination Survey. *Diabetes Care* **2004**, *27*, 2954-2959, 10.2337/diacare.27.12.2954.
11. Cristina Molina-Hidalgo; Alejandro De-La-O; Lucas Jurado-Fasoli; Francisco J. Amaro-Gahete; Manuel J. Castillo; Molina- Hidalgo; Jurado- Fasoli; Amaro- Gahete; Alejandro De-La-O; Beer or Ethanol Effects on the Body Composition Response to High-Intensity Interval Training. The BEER-HIIT Study.. *Nutrients* **2019**, *11*, 909, 10.3390/nu11040909.
12. Yamazaki, T.; Morimoto-Kobayashi, Y.; Koizumi, K.; Takahashi, C.; Nakajima, S.; Kitao, S.; Taniguchi, Y.; Katayama, M.; Ogawa, Y. Secretion of a gastrointestinal hormone, cholecystokinin, by hop-derived bitter components activates sympathetic nerves in brown adipose tissue. J. Nutr. Biochem. 2019, 64, 80–87.
13. Morimoto-Kobayashi, Y.; Ohara, K.; Ashigai, H.; Kanaya, T.; Koizumi, K.; Manabe, F.; Kaneko, Y.; Taniguchi, Y.; Katayama, M.; Kowatari, Y.; et al. Matured hop extract reduces body fat in healthy overweight humans: A randomized, double-blind, placebo-controlled parallel group study. Nutr. J. 2015, 15, 25.
14. Ayabe, T.; Ohya, R.; Kondo, K.; Ano, Y. Iso-α-acids, bitter components of beer, prevent obesity-induced cognitive decline. Sci. Rep. 2018, 8, 4760.
15. Miura, Y.; Hosono, M.; Oyamada, C.; Odai, H.; Oikawa, S.; Kondo, K. Dietary isohumulones, the bitter components of beer, raise plasma HDL-cholesterol levels and reduce liver cholesterol and triacylglycerol contents similar to PPARα activations in C57BL/6 mice. Br. J. Nutr. 2005, 93, 559–567.
16. Dostálek, P.; Karabín, M.; Jelínek, L. Hop phytochemicals and their potential role in metabolic syndrome prevention and therapy. Molecules 2017, 22, 1761.
17. Lenka Česlová; Michal Holčapek; Martin Fidler; Jitka Drštičková; Miroslav Lísa; Characterization of prenylflavonoids and hop bitter acids in various classes of Czech beers and hop extracts using high-performance liquid chromatography–mass spectrometry. *Journal of Chromatography A* **2009**, *1216*, 7249-7257, 10.1016/j.chroma.2009.09.022.
18. Obara, K.; Mizutani, M.; Hitomi, Y.; Yajima, H.; Kondo, K. Isohumulones, the bitter component of beer, improve hyperglycemia and decrease body fat in Japanese subjects with prediabetes. Clin. Nutr. 2009, 28, 278–284.
19. Vanhoenacker, G.; De Keukeleire, D.; Sandra, P. Analysis of iso-α-acids and reduced iso-α-acids in beer by direct injection and liquid chromatography with ultraviolet absorbance detection or with mass spectrometry. J. Chromatogr. A 2004, 1035, 53–61.
20. Pietschmann, P.; Rauner, M.; Sipos, W.; Kerschan-Schindl, K. Osteoporosis: An age-related and gender-specific disease—A mini-review. Gerontology 2009, 55, 3–12.
21. Biino, G.; Casula, L.; De Terlizzi, F.; Adamo, M.; Vaccargiu, S.; Francavilla, M.; Loi, D.; Casti, A.; Atzori, M.; Pirastu, M. Epidemiology of osteoporosis in an isolated sardinian population by using quantitative ultrasound. Am. J. Epidemiol. 2011, 174, 432–439.
22. Price, C.T.; Koval, K.J.; Langford, J.R. Silicon: A review of its potential role in the prevention and treatment of postmenopausal osteoporosis. Int. J. Endocrinol. 2013, 2013, 316783.
23. Fairweather-Tait, S.J.; Skinner, J.; Guile, G.R.; Cassidy, A.; Spector, T.D.; MacGregor, A.J. Diet and bone mineral density study in postmenopausal women from the twinsUK registry shows a negative association with a traditional english dietary pattern and a positive association with wine. Am. J. Clin. Nutr. 2011, 94, 1371–1375.

24. Hardcastle, A.C.; Aucott, L.; Reid, D.M.; MacDonald, H.M. Associations between dietary flavonoid intakes and bone health in a scottish population. J. Bone Miner. Res. 2011, 26, 941–947.

25. Welch, A.; MacGregor, A.; Jennings, A.; Fairweather-Tait, S.; Spector, T.; Cassidy, A. Habitual flavonoid intakes are positively associated with bone mineral density in women. J. Bone Miner. Res. 2012, 27, 1872–1878.

26. Effenberger, K.E.; Johnsen, S.A.; Monroe, D.G.; Spelsberg, T.C.; Westendorf, J.J. Regulation of osteoblastic phenotype and gene expression by hop-derived phytoestrogens. J. Steroid Biochem. Mol. Biol. 2005, 96, 387–399.

27. Xia, T.S.; Lin, L.Y.; Zhang, Q.Y.; Jiang, Y.P.; Li, C.H.; Liu, X.Y.; Qin, L.P.; Xin, H.L. Humulus lupulus, L. extract prevents ovariectomy-induced osteoporosis in mice and regulates activities of osteoblasts and osteoclasts. Chin. J. Integr. Med. 2019, 1–8.

28. Hiroyasu Tobe; Yoshifumi Muraki; Kazuyuki Kitamura; Osamu Komiyama; Yusuke Sato; Tatsuo Sugioka; Hiromi B. Maruyama; Eriko Matsuda; Masahiro Nagai; Bone Resorption Inhibitors from Hop Extract. *Bioscience, Biotechnology, and Biochemistry* **1997**, *61*, 158-159, 10.1271/bbb.61.158.

29. Lambert, M.N.T.; Hu, L.M.; Jeppesen, P.B. A systematic review and meta-analysis of the effects of isoflavone formulations against estrogen-deficient bone resorption in peri- and postmenopausal women. Am. J. Clin. Nutr. 2017, 106, ajcn151464.

30. Prouillet, C.; Mazière, J.-C.; Mazière, C.; Wattel, A.; Brazier, M.; Kamel, S. Stimulatory effect of naturally occurring flavonols quercetin and kaempferol on alkaline phosphatase activity in MG-63 human osteoblasts through ERK and estrogen receptor pathway. Biochem. Pharmacol. 2004, 67, 1307–1313.

31. Jeong, H.M.; Han, E.H.; Jin, Y.H.; Choi, Y.H.; Lee, K.Y.; Jeong, H.G. Xanthohumol from the hop plant stimulates osteoblast differentiation by RUNX2 activation. Biochem. Biophys. Res. Commun. 2011, 409, 82–89.

32. Kateřina Štulíková; Marcel Karabín; Jakub Nešpor; Pavel Dostalek; Therapeutic Perspectives of 8-Prenylnaringenin, a Potent Phytoestrogen from Hops. *Molecules* **2018**, *23*, 660, 10.3390/molecules23030660.

33. Luo, D.; Kang, L.; Ma, Y.; Chen, H.; Kuang, H.; Huang, Q.; He, M.; Peng, W. Effects and mechanisms of 8-prenylnaringenin on osteoblast MC3T3-E1 and osteoclast-like cells RAW264.7. Food Sci. Nutr. 2014, 2, 341–350.

34. Yu-Ming Chen; Suzanne C. Ho; Silvia S. H. Lam; Susan S. S. Ho; Jean L. F. Woo; Soy Isoflavones Have a Favorable Effect on Bone Loss in Chinese Postmenopausal Women with Lower Bone Mass: A Double-Blind, Randomized, Controlled Trial. *The Journal of Clinical Endocrinology & Metabolism* **2003**, *88*, 4740-4747, 10.1210/jc.2003-030290.

35. Giersch, G.E.W.; Charkoudian, N.; Stearns, R.L.; Casa, D.J. Fluid balance and hydration considerations for women: Review and ruture directions. Sport. Med. 2020, 50, 253–261.

36. Stachenfeld, N.S.; DiPietro, L.; Palter, S.F.; Nadel, E.R. Estrogen influences osmotic secretion of AVP and body water balance in postmenopausal women. Am. J. Physiol. Regul. Integr. Comp. Physiol. 1998, 274, 187–195.

37. Nina S. Stachenfeld; Hormonal Changes During Menopause and the Impact on Fluid Regulation. *Reproductive Sciences* **2014**, *21*, 555-561, 10.1177/1933719113518992.

38. Nina S. Stachenfeld; Andres E. Splenser; Wendy L. Calzone; Matthew P. Taylor; David L. Keefe; Selected Contribution: Sex differences in osmotic regulation of AVP and renal sodium handling. *Journal of Applied Physiology* **2001**, *91*, 1893-1901, 10.1152/jappl.2001.91.4.1893.

39. David Jiménez-Pavón; Mónica Sofía Cervantes-Borunda; Ligia Esperanza Díaz; Ascensión Marcos; Manuel J. Castillo; Effects of a moderate intake of beer on markers of hydration after exercise in the heat: a crossover study. *Journal of the International Society of Sports Nutrition* **2015**, *12*, 1-8, 10.1186/s12970-015-0088-5.

40. Shirreffs, S.M.; Maughan, R.J. The effect of alcohol on athletic performance. Curr. Sports Med. Rep. 2006, 5, 192–196.

41. Barnes, M.J.; Mündel, T.; Stannard, S.R. A low dose of alcohol does not impact skeletal muscle performance after exercise-induced muscle damage. Eur. J. Appl. Physiol. 2011, 111, 725–729.

42. Susan M. Shirreffs; Ronald J. Maughan; Restoration of fluid balance after exercise-induced dehydration: effects of alcohol consumption. *Journal of Applied Physiology* **1997**, *83*, 1152-1158, 10.1152/jappl.1997.83.4.1152.

43. Stefania Orrù; Esther Imperlini; Ersilia Nigro; Andreina Alfieri; Armando Cevenini; Rita Polito; Aurora Daniele; Pasqualina Buono; Annamaria Mancini; Role of Functional Beverages on Sport Performance and Recovery. *Nutrients* **2018**, *10*, 1470, 10.3390/nu10101470.

44. Flores-Salamanca, R.; Aragón-Vargas, L.F. Postexercise rehydration with beer impairs fluid retention, reaction time, and balance. Appl. Physiol. Nutr. Metab. 2014, 39, 1175–1181.

45. Castro-Sepulveda, M.; Johannsen, N.; Astudillo, S.; Jorquera, C.; Álvarez, C.; Zbinden-Foncea, H.; Ramírez-Campillo, R. Effects of beer, non-alcoholic beer and water consumption before exercise on fluid and electrolyte homeostasis in athletes. Nutrients 2016, 8, 345.

46. Wijnen, A.H.C.; Steennis, J.; Catoire, M.; Wardenaar, F.C.; Mensink, M. Post-exercise rehydration: Effect of consumption of beer with varying alcohol content on fluid balance after mild dehydration. Front. Nutr. 2016, 3, 45.
47. Desbrow, B.; Murray, D.; Leveritt, M. Beer as a sports drink? Manipulating beer’s ingredients to replace lost fluid. Int. J. Sport Nutr. Exerc. Metab. 2013, 23, 593–600.
48. Desbrow, B.; Cecchin, D.; Jones, A.; Grant, G.; Irwin, C.; Leveritt, M. Manipulations to the alcohol and sodium content of beer for postexercise rehydration. Int. J. Sport Nutr. Exerc. Metab. 2015, 25, 262–270.