THE EFFECT OF COFFEE ON METABOLIC RESPONSE AND EXERCISE IN VARIOUS ENVIRONMENTAL CONDITIONS: A SCOPING REVIEW

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by

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CERTIFICATE

This to certify that the dissertation entitled

The Effect of Coffee on Metabolic Response and Exercise in Various Environmental Conditions: A Scoping Review

Is the bona fide record of review done by

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DECLARATION

I hereby declare that this dissertation of my own review, except where otherwise stated and duly acknowledge. I also declare that it has not been previously and concurrently submitted for any other bachelors at Universiti Sains Malaysia or other institution. I grant Universiti Sains Malaysia has the right to use the dissertation for research, teaching, learning and promotional purposes.

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Nur Farainaa binti Wahab

Date : 23 June 2021

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Pendahuluan: Kopi terdiri daripada kafein yang berlaku secara semula jadi, dan diketahui dapat meningkatkan kadar metabolisme. Kafein, adalah salah satu makanan tambahan ergogenik yang paling biasa dalam sukan yang merupakan sifat yang dipercayai dapat meningkatkan prestasi senaman daripada kopi. Tinjauan ini bertujuan untuk menjelaskan penemuan mengenai kesan kopi, kafein dalam kombinasi dengan bahan tambahan, mengenai tindak balas metabolik dan prestasi latihan dalam pelbagai keadaan persekitaran. **Kaedah:** Tinjauan dicari berdasarkan PRISMA tinjauan skoping (PRISMA-ScR), menggunakan EBSCOhost, Science Direct, PubMed, dan Scopus dari penerbitan bahasa Inggeris dari 2015 hingga 2021. Dari 240 kajian yang disaring, hanya 20 penerbitan disertakan. **Hasil:** Terdapat lima kajian yang meneliti kopi, sembilan kajian menggunakan kafein dan makanan tambahan tanpa kafein. Enam melaporkan kesan gabungan kopi dengan suplemen tambahan semasa latihan (minyak kedelai dan kelapa tambahan, makanan berkarbohidrat (CHO) tinggi, CHO rendah kalori (0.4% larutan, 2g jumlah karbohidrat), aurantium sitrus, ekstrak kacang dekstrosa, biji kopi hijau, larutan CHO 6%). 13 kajian menyelidiki pengaruh kopi terhadap prestasi senaman (daya tahan, kekuatan, keletihan masa, prestasi senaman). Dua kajian menyelidiki kesan kopi terhadap peningkatan epinefrin dan norepinefrin dan tidak ada perbezaan yang signifikan terhadap insulin, glukosa dan trigliserida. Lima kajian menyelidiki perubahan metabolik yang menunjukkan pentingnya perbelanjaan tenaga, kepentingan kadar penggunaan yang dirasakan, tidak ada perbezaan pada kadar oksidasi lemak dan karbohidrat, tidak ada kepentingan pengambilan oksigen maksimum (VO2max). Pengambilan kafein 3 hingga 6 mg/kg.berat badan (BW) meningkatkan prestasi daya tahan dalam dua kajian, tiga dari empat kajian melaporkan peningkatan kekuatan dan kekuatan. Peningkatan masa prestasi didapati dalam tiga daripada lima kajian, dua kajian tidak menunjukkan peningkatan dalam prestasi latihan lontaran bebas dan pecut. **Kesimpulan:** Kopi atau zat yang ditambah dengan kafein meningkatkan prestasi sukan atau sukan dan metabolik. Pengambilan kafein dalam dos antara 3 hingga 6 mg/kg.bw menunjukkan prestasi latihan, darah, dan metabolik yang signifikan dalam 60 minit setelah pengambilan sebelum intervensi.

THE EFFECT OF COFFEE ON METABOLIC RESPONSE AND EXERCISE IN VARIOUS ENVIRONMENTAL CONDITIONS: A SCOPING REVIEW

ABSTRACT

Introduction: Coffee consists of caffeine which occurs naturally, and has been known to increase metabolic rate. Caffeine is one of the most common ergogenic supplements in sports whose properties believed able to enhance exercise performance better than consuming coffee. The aims to elucidate findings on the effects of coffee, caffeine in combination with additional substances, on metabolic response and exercise performance in various environmental conditions. **Methods:** Literature was searched based on PRISMA scoping review (PRISMA-ScR) using EBSCOhost, ScienceDirect, PubMed, and Scopus databases of English publications from 2015 to 2021 was conducted. From 240 studies screened, only 20 publications were included. **Results:** There were five studies investigated coffee, nine studies used caffeine and decaffeinated supplements. Six reported combined effects of coffee with an additional supplement on exercise (soy and extra virgin coconut oil, high carbohydrate (CHO) meal, low calorie CHO (0.4%solution, 2g total CHO), citrus aurantium, dextrose, green coffee-bean extract, 6%CHO solution). 13 studies investigated effect of coffee on exercise performance (endurance, strength and power, time-to-exhaustion). Two studies showed coffee enhanced epinephrine and norepinephrine but not insulin, glucose and triglycerides. Five studies investigated changes in metabolic which showed significant difference ($p<0.05$) in energy expenditure and rate of perceived exertion, but no differences on the rate of fat and CHO oxidations as well as maximal oxygen uptake (VO_{2max}). Acute ingestion of 3 to 6 mg/kg.body weight caffeine improved endurance performance in two studies, three studies improvements in strength and power ($p<0.05$). Improvement in time performance was found in three studies, two studies found no improvement in exercise performance of free-throw and sprinting. **Conclusion:** Coffee or supplements added with caffeine improved exercise or sport performance and metabolic. Caffeine ingestion in dosages between 3 to 6 mg/kg.bw showed significant changes in exercise performance, blood, and metabolic within 60 minutes of ingestion prior to intervention.

CHAPTER 1: INTRODUCTION

1.1 Background of the review

Caffeine occurs naturally in coffee, cocoa and tea and its presence in coffee has been known to increase metabolic rate, with the first research reported in year 1915 (Higgins and Means, 1915). Caffeine, a trimethyl xanthine stimulant, is one of the most common ergogenic supplements used in sports. The typical ergogenic doses of caffeine, between 3 to 6 mg/kg body weight? dose ingested 30 to 90 minutes before exercise, have been shown to improve performance by 6% in events lasting from a few minutes to several hours (Burke et al., 2013).

Caffeine has been frequently cited to induce its ergogenic effects by an increase in fat oxidation through the sympathetic nervous system and a sequential sparing of muscle glycogen (Spriet et al., 1992). The key mechanism by which caffeine is believed to exert its effect is via the antagonism of adenosine receptors, leading to increases in neurotransmitter release, motor unit firing rates, and pain suppression (Kalmar, 2005).

However, there is little evidence to support caffeine's ergogenic effects on fat oxidation (Graham and Spriet, 1991). Heat-acclimatised recreational runners that had an acute dose of 5 mg caffeine/kg/body weight (BW) could run for a significantly longer time before exhaustion in a hot and humid environment (Wong et al., 2010). Studies showed that higher doses of caffeine at 6 and 9 mg/kg BW did not provide exercise performance improvements but resulted in increased serum glycerol and free fatty acids (FFA) during exercise (Graham and Spriet, 1995; Roelands et al., 2011). Caffeine did not blunt core temperatures as body core temperatures were increased significantly from pre-exercise with or without caffeine ingestion in the heat (Wong et al., 2010).

Ingestion of caffeine in untrained women has shown an increased oxygen consumption (VO_2) during and after prolonged moderate exercise with increase plasma free fatty acids (FFA) metabolism that was depicted in the decreased respiratory exchange quotient (RER) (Donelly and McNaughton, 1992). A recent study showed that the smaller body surface area in the women population reduces for whole-body heat exchange that can exacerbate the metabolic heat production compared to men (Notley et al., 2019). Thus, caffeine may potentially be used to enhance the metabolic energy expenditure by blunting the sympathetic response.

There are increasing evidence about the important role of coffee in health, particularly in reducing the risk of developing metabolic syndrome. Metabolic syndrome is associated with diabetes, hypertension and obesity (Sharma et al., 2011). However, the outcome of using coffee are varied due to caffeine potency in coffee that may be altered by preparation such as brewing method or type (ref). The metabolic rate has been shown to increase significantly during the 3 hours after caffeine ingestion (Acheson et al., 1980). Yet, the outcome on body metabolism or sports performance may be varied due to differences of caffeine dosages in the coffee, exercise protocol and environmental conditions. Firstly, we hypothesise that coffee intake or performance enhancing caffeine dosage can improve metabolic parameter and sports performance regardless of environmental conditions. The purpose of this review is to synthesise the effect of coffee ingestion on metabolic responses, and exercise performance in various exercise conditions.

1.2 Problem Statement

Most of the previous coffee and metabolic studies measured blood parameter such as insulin, epinephrine and glucose to investigate coffee's benefits on metabolic health. However, the outcomes of coffee studies are varied depending on the frequency of the prescription or preparation of coffee solutions. After reading some literature, known that this could be due to the differences of caffeine dosages intake in coffee, frequency and timing of coffee intakes. Differences of coffee source and type such as coffee beans, powder forms and brewing methods may influence the caffeine contents. Hence, reviewing this information will assist in understanding the effectiveness of coffee on metabolic health and exercise performance which include of endurance, aerobic and strength.

1.3 Objectives of the review

i. Provide a brief synthesis of the effect of coffee intake on metabolic parameters [carbohydrate oxidation, fat oxidation, respiratory exchange ratio (RER), energy expenditure (EE), oxygen uptake (VO_2), blood glucose, lactate, insulin, epinephrine] and exercise performance.
ii. Compare differences in the caffeine intake dosage and timing of ingestion in exercise studies.
iii. Compare differences in the exercise protocol and environmental conditions (hot, humid climate versus cold) in coffee studies.

1.4 Research questions of the review

i. Does coffee ingestion improve metabolic parameters and exercise performance?

ii. What is the timing of intake and the minimum dosage of caffeine in coffee that improve metabolic response and exercise performance?

iii. What is the exercise protocol and environmental conditions that elicited positive effects of coffee ingestion on metabolic parameters and exercise performance?

1.5 The hypothesis of the review

i. Coffee significantly enhances metabolic parameters to improve sports performance:

   1a. An improvement of fat oxidation by sparing CHO oxidation.

   1b. Improvement of glucose uptake

   1c. Improvement of VO_2 consumption to improve sports performance.

ii. Sports or exercise performance is significantly enhanced when coffee is ingested before performing sports/exercise.

iii. Caffeine significantly enhanced sports or exercise performance in extreme environmental conditions (hot-humid and cold).

1.6 Significance of the review

The findings of this review will provide additional knowledge on the use of caffeinated coffee as an alternative method to improve the metabolic rate and energy expenditure by increasing carbohydrate and fat oxidation during exercise in the hot and humid Malaysian weather. These metabolic parameters are critical for reducing the risk of metabolic syndrome and regulating body weight. The outcome of this review will provide additional nutritional recommendation and knowledge to individuals who are occasional drinkers of coffee. In addition, coffee ingestion may be used as a therapeutic diet to improve metabolic health.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction to Coffee

Coffee is the second largest traded commodity globally after petroleum, and it accounts for US$10 billion annually. More than 70 countries cultivate this plant, with Brazil, Colombia, Ethiopia, and India as the leading producers and suppliers of coffee beans in the world (ICO, 2004). The coffee plant belongs to the family Rubiaceae and genera Coffea. It is a woody perennial tree that grows at higher altitudes. There are reportedly 70 different species of coffee beans, but the most commercially important are Coffea Arabica (arabica coffee) and Coffea canephora (robusta coffee). These two types differ in their taste, appearance, and caffeine contents (Petit, 2007). Arabica coffee beans account for 75 to 80% of the world consumed while the rest of the 20% market share has been captured by robusta coffee. Robusta coffee produces an inferior tasting beverage with higher caffeine contents, and also tocopherols or vitamin E contents of Arabica are also higher than robusta coffee (Alves et al., 2009). Processing of coffee involves picking the bean, drying, roasting, grinding, and brewing to yield the final beverage. Decaffeination and filtration are carried out sometimes to remove components such as caffeine and lipid fractions. Coffee bean processing consists of several physical and chemical changes that may affect the flavour and chemical properties of the final product (Sacchetti et al., 2009; Parras et al., 2007).

Caffeine (chemical formula $C_8H_{10}N_4O_2$), with its molecular mass of 194.19 g/mol is the main components of coffee content (ref). The caffeine molecule is a typical natural alkaloid, formed by a pyrimidinedione (6-member ring with two nitrogen atoms) and an imidazole (5-member ring with two nitrogen atoms) rings that are fused while other components in coffee that also plays a central role in health, i.e., chlorogenic acid (3-3,4-Dihydroxycinnamoyl quinic acid), caffeic acid (3,4-Dihydroconnamic acid), and hydroxyhydroquinone (1,2,4-Trihydroxybenzene). These components are potent antioxidants and impart certain health benefits such as protecting the body from the hazardous effects of free radicals, and their effectiveness against diabetes mellitus and cardiovascular disparities is well accepted (Brezov´a et. al., 2009; Suzuki et al., 2008; Farah and Donangelo, 2006). Caffeine (1,3,7-trimethylxanthine) is one of the most consumed ergogenics globally and can be found in many foods and beverages, such as chocolate, teas, guarana, and coffee (Peeling et al., 2018).

The health benefits of caffeinated coffee are often attributed to chlorogenic acid as the lignans and some mineral segments possess therapeutic potential (Celik et al., 2009; Suzuki et al., 2008; Farah & Donangelo, 2006). These components showed protective properties against cardiovascular diseases, diabetes mellitus, Parkinson's disease, Alzheimer's disease, DNA damage, as well as an enhanced antioxidant status of the body (Conney et al., 2007). Coffee is the richest source of caffeine and an active alkaloid.

Frary et al. (2005) conducted a survey regarding caffeine intake from various sources and reported that 70% of caffeine comes from coffee while soft drinks and tea contribute to 16% and 12% respectively, and caffeine produces alertness through stimulating functions and is an effective stimulant to invigorate fatigued individuals.

2.2 Effect of Caffeinated Coffee on Exercise Performance in Various Environmental Conditions

Caffeine has been widely used as an ergogenic aid to increase physical performance. It is available in different forms, such as gels, gums, powders, bars, and energy drinks (Wickham and Spriet, 2018). Clarke et al. (2017) investigated the effects of caffeinated coffee (containing 3 mg/kg BW.), decaffeinated coffee and placebo after one hour of rest from 1-mile race performance and found that caffeine ingestion led to a 1.3% and 1.9% faster performance in a race when compared to decaffeinated or a placebo (water), respectively.

There were reportedly 89% and 73% of the athletes using caffeinated substances (cola drinks (78%), caffeinated gels (42%), coffee (usually pre-race) (37%), energy drinks (13%), and NoDoz tablets (9%) in the 2005 Triathlon World Championships and 2005 Ironman Triathlon World Championships which consist of 3.8 km swim, 180 km cycle, and a 42.2 km run, respectively, with the purpose to enhance their endurance performance (Desbrow and Leveritt, 2006; Desbrow and Leveritt, 2007). Ingestion of 5 mg caffeine/kg BW has the most consistent effect of boosting endurance performance (Trice and Haymes, 1995; Ransley et al., 2005).

In a hot and humid environment, ingestion of 5 mg of caffeine for per kg BW improved the endurance running performance in heat-acclimated recreational Malaysian runners, but not the cardiorespiratory parameter such as the maximal oxygen consumption (VO_2max) that refer to the ability of the circulatory and respiratory systems to supply oxygen to skeletal muscles during sustained physical activity (Wong et al., 2010). Caffeine's potency to improve exercise performance could be enhanced with herbal supplements. The supplementation in herbs like mahuang, ephedrine and related alkaloids did not enhance the endurance performance; but if they were supplemented along with caffeine, endurance performance was increased (Bucci, 2000).

Graham et al. (1998) showed that running time to exhaustion at 80% VO_2max following the ingestion of anhydrous caffeine in capsules was improved by 31% when compared to placebo and 23% compared to decaffeinated coffee ingestion. In addition, a study by Temple and Ziegler (2011) reported men and women differ in their cardiovascular and perceptual responses to caffeine (2 mg/kg), which may be mediated by changes in circulating steroid hormones, potentially affecting exercise performance.

Conversely, a study which dissolved higher caffeine dose of 10 mg/kg BW, intake has no effect on VO_2 peak, heart rate, sweat rate and rectal temperature during an exercise tolerance test in hot and humid environmental condition (Dunagan et al., 1998). High doses of caffeine might end in urine caffeine concentrations greater than 15 µg/ml, which is prohibited in the National Collegiate Athletic Association (NCAA) (The National Collegiate Athletic Association, 2019).

When specifically examining endurance performance, the major mechanism hypothesised to account for much of caffeine’s benefits on performance is its ability to regulate perceptual responses such as pain, fatigue, and feelings of vigour (Goldstein et al., 2010). This is thought to be achieved through the antagonistic effect it has on adenosine receptors A1 and/ or A2a according to Lynge and Hellsten (2000). The blockade of adenosine through caffeine’s ability to freely cross the blood-brain barrier is augmented by its muscular metabolic effects, leading to the enhanced excitation-contraction coupling of skeletal muscle, potentiation of muscle force, work, and power (Spriet, 1995; Tallis et al., 2015).

Findings from study by Motl et al., (2003), admitted a significant reduction in leg muscle pain when 10 mg/kg caffeine was ingested before 30 min of submaximal cycling among cyclists. The magnitude of leg pain induced by repeated contractions of the fatigue inducing exercises after the intake of drugs such as caffeine or aspirin was reduced (Hudson et al., 2008). Caffeine reduces pain perception by blocking pronociceptive adenosine receptors. Adenosine concentration increases in the muscle during moderate- or high-intensity exercise and binds to adenosine receptors on the sensory nerve endings that can result in pain signaling. By blocking these receptors, caffeine inhibits pain perception (Myzers et al., 1997; Noakes et al., 2004).

When the caffeine dose was reduced to a moderate level between 5 to 6 mg/kg body mass, the ergogenic effects were sustained, and the physiological responses and side effects were also reduced but were still present (Graham et. al., 2000). Prior to a maximum effort run, caffeine consumption of 5 mg/kg body weight roughly 295 mg caffeine for a 130 lb. female, or about three cups of coffee resulted in significantly greater anaerobic metabolism and improved athletic performance among recreational runners (Doherty, 1998).

In addition, a study conducted on cyclists found that consuming 6 mg caffeine/kg bw (about 355 mg for a 59 kg person, or three to four cups of coffee) improved performance times during a cycling trial, regardless of whether caffeine was ingested one hour before exercise or in a series of doses throughout the trial (Cox et. al., 2002). Thus, administered amounts of 5 to 6 mg/kg caffeine solution has been advised to produce ergogenic effects during soccer match simulation on three separate occasions in soccer players (Kingsley et.al., 2014).

As we can conclude from all findings about caffeine and performance, most studies reported that with ingestion of caffeine can improve endurance performance such 1-mile race, Triathlon with include of cycling and swimming, soccer and others. Most of studies were lack of environmental data which are temperature and humidity of exercise, so due to this insufficient information, it will be good to review these conditions.

2.3 Effect of caffeine ingestion on the metabolic responses during exercise in the various environmental conditions

The potential ergogenic mechanisms of caffeine have been studied including: 1) increased free fatty acid oxidation; 2) alteration of mechanisms within skeletal muscle related to the regulation of carbohydrate breakdown (Manore et al., 2009); and 3) raised mobilisation of intracellular calcium (Ganio et al., 2009).

Antagonistic effects of caffeine on adenosine receptors may reduce the antilipolytic effects of adenosine on adipose tissue, further increasing FA breakdown (Duncan et al., 2013). During exercise, caffeine can reduce the use of the glycogen and increase the release of free fatty acids, which might delay fatigue and increase endurance (Bishop D., 2010).

Previous evidence reported that the source of energy utilisation changed after caffeine supplementation from alternating carbohydrate to lipid by increasing muscle uptake, and then fat oxidation, which leads to intramuscular glycogen sparing through the Randle effect (Costill et al., 1978). The administration of a low caffeine dose, 3 mg/kg bm has shown to produce an ergogenic effect, with no changes in exercise heart rate and the levels of catecholamines, lactate, FFA, and glycerol (Graham & Spriet, 1995).

Reductions in body fat have been reported when the sprint interval training (SIT) intervention is longer (e.g., 4 weeks). Thus, it appears that a SIT-induced reduction in body fat typically requires more than two weeks of training (Ferreira et al., 2019).

A study by Graham et al., (1998) showed that running time to exhaustion (85% VO_2max) was only improved when runners ingested caffeine (CAF), which is 4.5 mg CAF/kg BW, prior to exercise, but not when they ingested either regular coffee (4.5 mg CAF/kg BW), decaffeinated coffee (DECOF) plus caffeine (4.5 mg CAF/kg BW), decaffeinated coffee and placebo control. The authors reported that the contrast in performance could not be explained by the caffeine 1 h following intake or at the end of the exercise, as no difference was observed between trials that contained caffeine. However, high caffeine doses of 6 and 9 mg/kg BW resulted in the increases of serum glycerol and free fatty acids (Graham et al., 1995; Roelands et al., 2011).

Thus, demonstrated that increasing doses of caffeine resulted in increasing circulating concentrations of caffeine which caffeine components itself plays role in sympathetic nervous system (SNS) by mediated glucose release (Petersen et al., 2017). Blood lactate concentration being higher at the completion of the coffee trial, no differences in heart rate were observed (Hodgson et al., 2013).

Higher plasma lactate concentration during the caffeine trials might be the result of enhanced muscle glycogenolysis, accompanied by an inability of the mitochondria to absorb ang gains the increased pyruvate production for aerobic ATP resynthesis (Hadjicharalambous et al., 2006).

Although it has already been observed that acute supplementation of caffeine (5 mg/kg of BW) one hour prior to exercise may improve performance in high-intensity cycling with low carbohydrate availability through enhanced anaerobic contribution (Silva-Cavalcante et. al, 2013). In addition, evidence suggests that caffeine supplementation (5 mg/kg of BW) may increase performance, as well as anaerobic energy sources, in high intensity running (Doherty, 1998). During exercise, caffeine can reduce the use of the glycogen and increase the release of FFA (Goldstein et. al., 2010), which might delay fatigue and increase endurance.

In a meta-analysis of 21 studies by Doherty and Smith (2005), a significant collective reduction in the rate of perceived exertion (RPE) during submaximal aerobic exercise with caffeine was observed versus placebo. Caffeine was said to induce its ergogenic effects by an increase in fat oxidation through the sympathetic nervous system, and a sequential sparing of muscle glycogen (Spriet, et al. 1992). In men, caffeine did not blunt core temperatures as body core temperatures were increased significantly from pre-exercise with or without caffeine ingestion in the heat (Wong et al., 2010). The smaller body surface area of women reduced whole-body heat exchange that can exacerbate the metabolic heat production compared to men (Notley, et al., 2019). Exercise in hot and humid conditions may produce significant heat stress that increases plasma epinephrine that may alter metabolic responses that could negatively affect the rate of metabolic energy expenditure.

Ingestion of caffeine in untrained women have shown an increased oxygen consumption ($V?O_2$) during and after prolonged moderate exercise while plasma free fatty acids (FFA) was increased and respiratory exchange quotient (RER) was decreased (Donelly, and McNaughton, 1992). By enhancing the fat oxidation through caffeine ingestion, healthy body weight in women may be more effectively maintained, especially those who are regularly exercising at moderate intensity. Hence, caffeine may be potentially used as a dietary intervention to enhance metabolic energy expenditure.

While studies have previously shown acute coffee caffeine consumption to negatively affect glucose metabolism in healthy subjects (Moisey et al, 2008) evidence from more recent studies has demonstrated a decreased risk of type 2 diabetes mellitus, following regular consumption of caffeinated coffee and even decaffeinated coffee. (Huxley et al., 2009; Wedick et al., 2011).

CHAPTER 3: METHODOLOGY

3.1 Data Sources

Related studies were search electronically using the following databases: PubMed, Science Direct, Scopus and EBSCOhost. Briefly, the selected studies were searched using the same selection criteria as described below. In addition, cross referencing related previously published study was performed of obtain extra information. Peer reviewer articles in English language from January 2015 until January 2021 were used. No attempts were made to contact authors for additional information. Comparable searches were made for the other database (SPORTDiscuss).

3.2 Study Selection

The search was conducted according to the PRISMA for scoping review (PRISMA-ScR) out in 2018 publication guidelines. The following keywords were used during the search: #coffee, #caffeine, #metabolic and #exercise performance. Studies were screened for employing coffee as an intervention and metabolic as outcomes of measure. Controlled trials and laboratory studies on human only included in this review. The intervention comprised: (i) caffeinated coffee and (ii) decaffeinated coffee.

Metabolic described as: (1) VO_2, (2) carbohydrate oxidation, (3) fat oxidation, (4) respiratory exchange ratio (RER), energy expenditure (EE), blood glucose, lactate, insulin, epinephrine and exercise performance.

Exercise performance or physical activity described as: (1) time taken, (2) aerobic performance, (3) anaerobic or explosive activity, (4) resistance training, or (5) sports specific performance tests.

3.3 Data Extraction

The titles and abstracts of retrieved article were reviewed using the criteria specified to determine whether full texts were required for further analysis. Each full-text manuscript was evaluated systematically according to the study: (1) objective/s, (2) characteristics of the study (targeted population, age, sample size and study design), (3) content of intervention (intervention types, duration of intervention and protocol intervention), (4) targeted outcome/s, and (5) main findings. The outcomes extracted from those studies were not combined, reanalysed or change due to the nature of this scoping review.

3. 4 PRISMA Flow

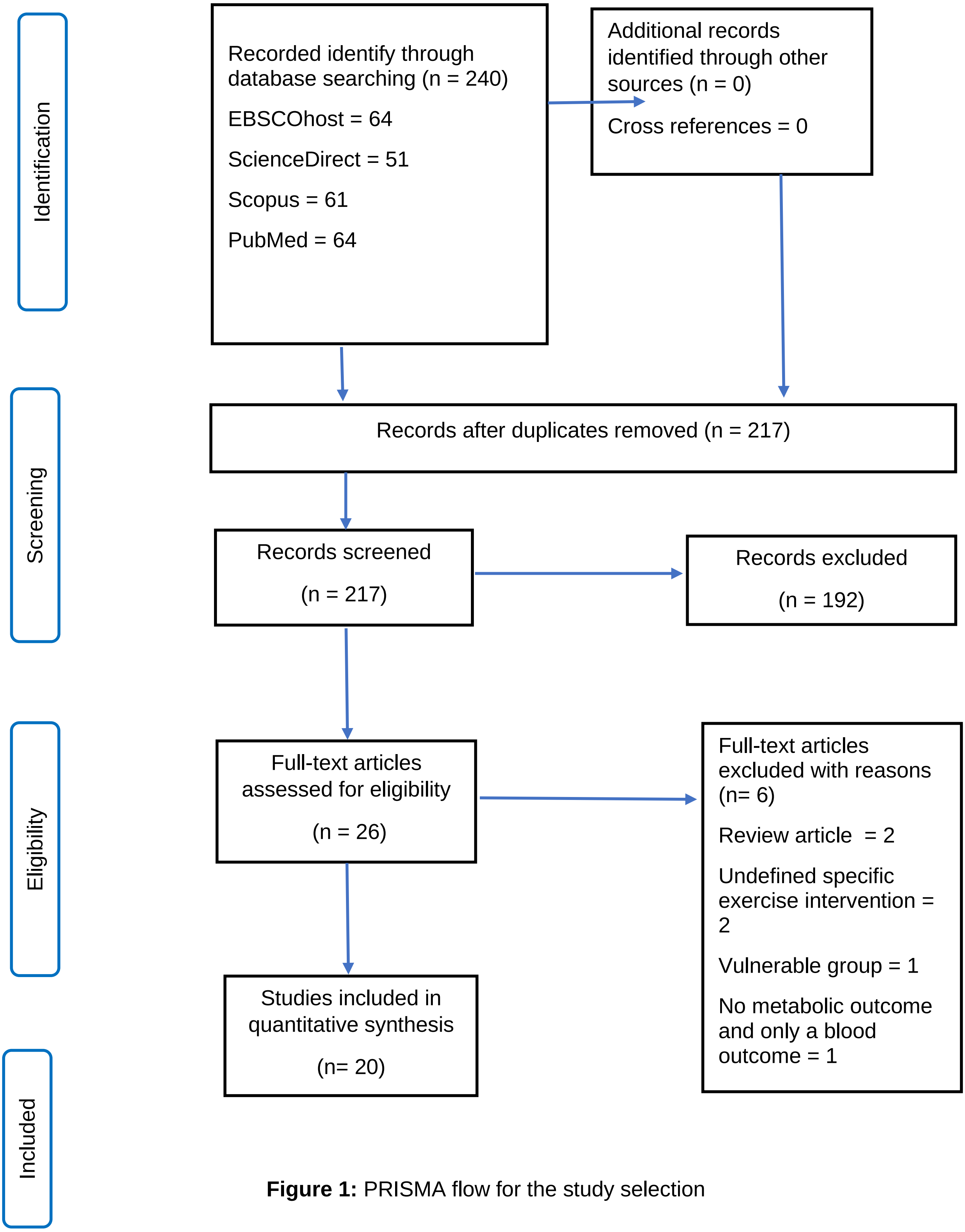

Figure 1: PRISMA flow for the study selection

CHAPTER 4: RESULT

4.1 Search Results

The initial search from the databases identified 240 potential articles while no article was found through cross referencing. After removing duplicates, 217 articles were assessed based on titles and abstracts against the selection criteria. A total of 192 articles were excluded because they did not investigate on coffee/caffeine and blood or metabolic parameter when exercising. After detailed analysis of the 26 full-text articles only 20 were included in this scoping review. The excluded articles were review article, undefined specific exercise intervention, vulnerable group and no metabolic data and only a blood outcome data. *Figure 1* describes the PRISMA flow diagram for the study selection.

From the 20 studies reviewed, all studies were conducted on humans. The scope of study from those retrieved articles was primarily on the effects of coffee or caffeine ingestion either caffeinated or decaffeinated or additional supplements on exercise performance, blood and metabolic parameter.

Research Designs

The majority of the research obtained from the search are randomised controlled (12 studies, 60%), while the others are crossover / counterbalance studies (4 studies, 20%), repeated measure (4 studies, 20%) and experimental study (1 study, 5%).

Types of Coffee used and in combination with other supplemental forms

From the database search, there are only five studies which uses coffee only (Marques et al., 2018; Clarke et al., 2019; Clarke et al., 2017; Harty et al., 2020; Church et al., 2015) while nine studies use caffeine and decaffeinated non-coffee substances (Apostolidis et al., 2020; Rossi et al., 2017; Ferreira et al., 2019; Beaumont R.E. & James L.J., 2017; Tan et al., 2020; Graham-Paulson et al., 2016; Fernández-Elías et al., 2015; Clark et al., 2020; Ali et al., 2016). Studies that combined coffee with other supplements were also found among these selected articles. One study used coffee in combination with soy oil and extra virgin coconut oil (Borba et al., 2019). The other five studies used caffeine with other food supplement forms such as caffeine with high carbohydrate meal (Hulton et al., 2020), caffeine with low calorie CHO (LCHO) (0.4% solution, 2 g total CHO) (Kumar et al., 2019), caffeine with citrus aurantium known as bitter orange fruit (Kliszczewicz et al., 2019), dextrose with caffeine and green coffee bean extract (Beam et al., 2015), and caffeine with 6% CHO solution (Keane et al., 2020).

From all the 20 included articles, there were six articles reported the use of caffeine in capsule form (Apostolidis et al., 2020; Rossi et al., 2017; Beaumont R.E. & James L.J., 2017; Graham-Paulson et al., 2016; Ali et al., 2016; Keane et al., 2020) and an article reported the use of powder form (Beam et al., 2015). Three articles reported the use of soluble coffee (Marques et al., 2018; Borba et al., 2019; Clarke et al., 2019). Two studies only used coffee and decaffeinated coffee (Clarke et al., 2017; Church et al., 2015). There was a study that used coffee beverage in combination with protein (Bang® Keto Coffee; 130 kcal, 300 mg caffeine, 20 g protein) or placebo (30 kcal, 11 mg caffeine, 1 g protein) (Harty et al., 2020) and a study used thermogenic fitness drink formulas (TFD) that contains caffeine (Clark et al., 2020). There were four studies that reported the use of caffeine with other supplements (high CHO meal solution, low-calorie CHO solution, cellulose capsule) (Hulton et. al., 2020; Kumar et. al., 2019; Ferreira et al., 2019) and there was a study used caffeine solution (Tan et al., 2020). Last but not least, there were two studies reported only using ingestion of caffeine either solution or capsule and placebo only (Apostolidis et. al., 2020; Fernández-Elías et. al., 2015)

Dosage

Most of included articles used 5 mg/kg BW of caffeine (Marques et al., 2018; Hulton et al., 2020; Rossi et al., 2017; Ferreira et al., 2019; Beam et al., 2015) and 6 mg/kg bw of caffeine (Borba et al., 2019; Apostolidi et al. 2020; Beaumont R.E. & James L.J., 2017; Tan et al., 2020; Ali et al., 2016) in their studies. While there were three articles used 3 mg/kg bw of caffeine (Kumar et al., 2019; Clarke et al., 2019; Church et al., 2015) and a study used 4 mg/kg BW of caffeine in their study (Graham-Paulson et al., 2016). Fernández-Elías et al., (2015) reported that the ingestion of 4.5 mg/kg BW of caffeine has a better outcome than 0, 0.5, 1.5 and 3.0 mg/kg BW of caffeine.

Besides that, there were four studies which used caffeine with others supplement like Citrus Aurantium plus 100mg of caffeine (CA + C) (Kliszczewicz et al., 2019), beverage (Bang® Keto Coffee 130 kcal) plus 300 mg caffeine and 20 g protein (Harty et al., 2020), Thermogenic fitness drink formulas (TFD) containing 140 mg or 100 mg of caffeine per serving? (Clark et al., 2020) and intake of 6% CHO solution plus 200 mg caffeine (Keane et al., 2020).

Irwin et al., (2011) reported that 3 mg/kg dose of caffeine has significantly improve exercise performance (completing a cycling time trial at a set amount of work as fast as possible, equivalent to one hour of cycling at 75% peak power output) irrespective of whether 4 days caffeine withdrawal period was imposed on habitual caffeine users. Trexler et al., (2016) concluded that providing 3 to 5 mg/kg of caffeine in the form of coffee or anhydrous caffeine improved repeated sprint performance.

Timing

Most studies have had the participants ingest a caffeine dose, rest an hour, and then continue with exercise or intervention (Marques et al., 2018; Borba et al., 2019; Clarke et al., 2019; Clarke et al., 2017; Ferreira et al., 2019; Beaumont R.E. & James L.J., 2017; Tan et al., 2020; Fernández-Elías et al., 2015; Church et al., 2015; Ali et al., 2016; Keane et al., 2020). This protocol has been selected because of caffeine is rapidly absorbed and plasma concentrations of caffeine approximate to a maximum level in an hour. This timing for caffeine administration and exercise of studies may be optimal.

Two studies had participants ingest caffeine 40 minutes before exercise (Hulton et al., 2020; Kumar et al., 2019) and two studies had participants ingest caffeine 45 minutes before exercise (Kliszczewicz et al., 2019; Graham-Paulson et al., 2016). Three studies did not state the timing for caffeine ingestion (Apostolidis et al., 2020; Rossi et al., 2017; Harty et al., 2020) and another study had three timing for post ingestion which are 30, 60 and 90 minutes after exercise (Clark et al., 2020).

Coffee/Caffeine Ingestion on Blood Parameter

Table 1 shows summarise of effects of coffee or caffeine consumption on blood parameter which include of blood glucose, lactate, epinephrine and insulin. An acute ingestion of caffeine (~ 3.0 to 6.0 mg/kg bw) led to improved significant outcomes in blood parameters.

Ten studies reported changes in blood glucose either in caffeinated, decaffeinated (Marques et al., 2018) or placebo (Kliszczewicz et al., 2019) trials. Nine studies reported changes in lactate concentration after intervention. Most of studies showed enhancement of lactate level (Hulton et al., 2020; Kumar et al., 2019; Apostolidis et al., 2020; Rossi et al., 2017; Clarke et al., 2017; Graham-Paulson et al., 2016) while two studies showed no significant outcome (Clarke et al., 2019; Keane et al., 2020) and a study showed no difference in results (Marques et al., 2018)

Three studies reported change in insulin which two of these was showed no change or no difference (Kliszczewicz et al., 2019; Ali et al., 2016) while the other one showed no significant outcome (Beam et al., 2015). Two studies reported change in epinephrine (Apostolidis et al., 2020) and norepinephrine levels which showed enhancement in result after intervention (Kliszczewicz et al., 2019).

Coffee/Caffeine Ingestion on Metabolic Parameter

Table 2 shows summarises of effects of coffee or caffeine consumption on metabolic which include of fat and carbohydrate oxidation, energy expenditure VO_2max, (rating of perceived exertion) RPE and (respiratory exchange ratio) RER.

An acute ingestion of caffeine (~ 3.0 to 6.0 mg/kg BW) led to improved significant outcome in metabolic changes while three studies ingested ~100 mg to 300 mg combined with other supplements such as protein, fitness drink and carbohydrate (Harty et al., 2020; Clark et al., 2020; Keane et al., 2020).

Three studies reported a change in carbohydrate oxidation after intervention. All of these studies showed no significant differences in the outcome (Apostolidis et al., 2020; Beaumont & James, 2017; Hulton et al., 2020). Four studies reported measure of fat oxidation however the outcome similar to carbohydrate oxidation which no difference result (Apostolidis et al., 2020; Beaumont & James, 2017; Hulton et al., 2020; Clark et al., 2020).

Besides, five studies reported changes in energy expenditure (EE). Three of these studies showed no difference (Apostolidis et al., 2020; Ferreira et al., 2019; Clark et al., 2020) in EE while a study showed significant result and (Harty et al., 2020) and two studies showed improvement in EE in post-ingestion (Ferreira et al., 2019; Fernández-Elías et al., 2015).

Two studies reported change in RER, one of these showed improvement (Church et al., 2015) while the other one showed significant outcome (Keane et al., 2020). Four studies reported change either higher or lower in RPE, two studies showed no difference (Beaumont & James, 2017; Tan et al., 2020), a study showed significant result (Borba et al., 2019) and a study showed lower during pre-intervention but not in post-intervention (Graham-Paulson et al., 2016).

Last but not least, two studies reported maximum oxygen uptake (VO_2max). A study showed no difference (Clark et al., 2020) while other one showed significant outcome (Keane et al., 2020).

4.2 TABLE RESULT

Table 1. A summary of studies that generally compared the blood changes of caffeine.

Reference	Participants	Dosage	Environment (Temperature and Humidity)	Protocols	Key result (only blood parameter changes with p value and figure)
Marques et al., (2018)	12 healthy adult M amateur endurance runner	soluble CAF (5.5 mg/kg BW? of CAF) @ decaf and after 60 min run	Temp: 21.38 ± 0.49 °C RH: 88.33 ± 3.76%	800-m run with overnight-fasting	Glu concentrations increased immediately after the race in the decaf (basal: 86.6 ± 16.69 vs. final: 113.0 ± 11.27 mg/dL, $p < 0.0001$) & caf (basal: 81.92 ± 12.02 vs. final: 107.75 ± 13.08 mg/dL, $p < 0.0001$) groups, without differences between the trial groups Lactate concentrations enhanced immediately after the race in the decaf (basal: 0.78 + SD vs. final: 9.14 + 6.97 nmol/L, $p = 0.0007$) & caf (basal: 1.28 + 0.88 vs. final: 9.34 + 6.07 nmol/L, $p = 0.0004$) groups, with no difference between trial
Hulton et al., (2020)	8 M recreational soccer players	a high-CHO meal, with pla @ 5mg/kg BM^{-1} caf	n.d.	85-min soccer simulation followed by an exercise capacity test (Yo-yo Intermittent	Rates of CHO and fat oxi did not differ between conditions and nor were differences apparent

				Endurance test level 2) on two occasions	for plasma glu. An increase in lac for CAF ($p=0.039$) all plasma metabolite concentrations increased from the start of ex and thereby produced sig time effects (plasma glu $p<0.001$; FA $p<0.001$, glycerol $p<0.001$, β-hydroxybutyrate $p=0.003$, lactate $p<<0.001$)
Kumar et al., (2019)	12 endurance trained (ET) & 12 healthy sedentary (SED) M (n = 10) and F (n = 2)	caf (3 mg/kg of BM, equivalent to 1.5 cups premium brewed cof), low calorie CHO (LCHO) (0.4% solution, 2 g total cho), caf + LCHO, and artificially sweetened pla	n.d.	4 ex trials consisting of 30 min cycling at sstandardised matched work rates 10% below lac threshold (MOD-EX) followed by a time to fatigue (TTF) ride at individually prescribed intensity of 5% above lac threshold.	Blood glu and lactate were higher ($p < 0.05$) with CAF vs. no-CAF. SED and ET only differed in metabolic oxidation rates during ex (higher overall fat oxidation with ET compared to SED).
Apostolidis et al., (2020)	20 M soccer players	6 $mg{\cdot}kg^{-1}$ of caffeine or pla	n.d.	2 trials simulating the cardiovascular demands of a soccer game to exhaustion on treadmill	Lac (3.3 ± 1.2 vs 2.9 ± 1.2 $mmol{\cdot}l^{-1}$) higher. Plasma glycerol, EE was not affected by CAF ($p > 0.05$). Non-esterified FA and epi plasma glu exhibited sig main effects of treatment [$F(1, 18) = 14.30$, $p = 0.001$, ES = 0.443]