

## **Theobroma cacao: Review of the Extraction, Isolation, and Bioassay of Its Potential Anti-cancer Compounds**

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**Abstrak:** Tumbuh-tumbuhan merupakan satu sumber yang terbaik untuk agen terapeutik sejak beribu-ribu tahun; banyak ubatan moden yang digunakan untuk merawat penyakit manusia berasal daripada sumber semula jadi. Pokok *Theobroma cacao*, atau koko, telah baru-baru ini mendapat perhatian yang semakin meningkat dan menjadi subjek penyelidikan kerana mempunyai sifat-sifat antioksidan, yang mempunyai kesan-kesan anti-kanser yang berpotensi. Pada tahun-tahun kebelakangan ini, pengenalpastian dan pembangunan sebatian aktif atau ekstrak-ekstrak daripada biji koko yang dapat memberi kesan anti-kanser telah menjadi bidang penting dalam penyelidikan berkaitan kesihatan dan bioperubatan. Ulasan ini memberikan gambaran keseluruhan terkini terhadap *T. cacao* dari segi potensi sebatian anti-kansernya dan pengekstrakan, bioesei *in vitro*, penulenan, dan pengenalpastian. Artikel ini juga membincangkan kebaikan dan keburukan teknik-teknik yang diterangkan dan memberi ulasan berkaitan proses-proses bagi perspektif kaedah analisis pada masa depan dari sudut pandangan penemuan sebatian anti-kanser.

**Kata kunci:** Produk Semula Jadi, Anti-kanser, *Theobroma cacao*

**Abstract:** Plants have been a good source of therapeutic agents for thousands of years; an impressive number of modern drugs used for treating human diseases are derived from natural sources. The *Theobroma cacao* tree, or cocoa, has recently garnered increasing attention and become the subject of research due to its antioxidant properties, which are related to potential anti-cancer effects. In the past few years, identifying and developing active compounds or extracts from the cocoa bean that might exert anti-cancer effects have become an important area of health- and biomedicine-related research. This review provides an updated overview of *T. cacao* in terms of its potential anti-cancer compounds and their extraction, *in vitro* bioassay, purification, and identification. This article also discusses the advantages and disadvantages of the techniques described and reviews the processes for future perspectives of analytical methods from the viewpoint of anti-cancer compound discovery.

**Keywords:** Natural Products, Anti-cancer, *Theobroma cacao*

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## INTRODUCTION

Cancer is characterised by the proliferation of abnormal cells that fail to respond correctly to normal regulatory mechanisms. Carcinogenesis, which describes cancer development, is a multi-step process consisting of the initiation, promotion, and progression of uncontrolled cell growth (Bennett *et al.* 2012; Plankar *et al.* 2011). Every year, there are 10 million new cancer cases and 7.6 million cancer-related deaths (13% of all deaths) worldwide; it has been estimated that there will be 12 million deaths in 2030 (Pujol *et al.* 2007; Talaviya 2011). In Malaysia, a total 18,219 new cancer cases were diagnosed in 2007, involving 8,123 males (44.6%) and 10,096 females (55.4%). The 10 leading cancers among the Malaysian population are breast, colorectal, lung, nasopharynx, cervical, lymphoma, leukaemia, ovarian, stomach, and liver cancer, and the five leading cancers among the general Malaysian population are cancer of the breast (18.1%), head and neck (13.2%), colorectum (12.3%), trachea, bronchus, and lung (10.2%), and cervix (4.6%) (National Cancer Registry 2011).

Plants have been used for medicine for thousands of years and remain relevant as natural sources of active compounds for treating human diseases, especially cancer (Cragg *et al.* 1997; Cragg & Newman 2013). As reported previously (Kinghorn *et al.* 1999; Kinghorn 2000; Cragg & Newman 2005), plant natural products have played an important role among the many recent advances in cancer chemotherapy, having contributed considerably to the approximately 60 available cancer chemotherapeutic drugs. There are currently four structural classes of plant-derived anti-cancer agents on the market in the USA, specifically the *Catharanthus* (vinca) alkaloids (vinblastine, vincristine, vinorelbine), epipodophyllotoxins (etoposide, etopophos [etoposide phosphate], teniposide), taxanes (paclitaxel, docetaxel), and camptothecin derivatives (topotecan, irinotecan). Many current cancer research studies investigating the chemotherapeutic potential of medicinal plants have been carried out to discover new therapeutic agents or complementary alternative medicines that lack the toxic effects of chemotherapeutic drugs and exert the same or better curative effects associated with current synthetic therapeutic agents (Rao *et al.* 2008; Mahavorasirikul *et al.* 2010). In the early stage of discovery, plant-derived anti-cancer agents are evaluated by screening their activity, which is based on their anti-proliferative effects. Such potential anti-cancer compounds are also investigated to elucidate their mechanism of action against various cancer cells.

The tropical tree *Theobroma cacao*, known as cacao or cocoa, belongs to the family Sterculiaceae, order Malvales. The cocoa tree originated from ancient Central America, where the Mayans and Aztecs cultivated it for its seeds, which they used for extracting a drink called *chocolatl*, a precursor to the modern chocolate. The Olmecs and Mayans believed that cacao was of divine origin. *Theobroma* means "food" (from the Greek *broma*) "of the gods" (from the Greek *theo*), and *cacao* is derived from the Aztec Nahuatl word *xocolatl*, from *xococ* (bitter) and *atl* (water). The *T. cacao* tree is a small evergreen tropical and subtropical tree that originates from neotropical rainforests, primarily in the Amazon basin and the Guyana Plateau (Bhattacharjee & Kumar 2007; Zhang *et al.* 2011; Grassi & Ferri 2012). In Malaysia, the first cocoa tree (Fig. 1) was

planted in Malacca in 1778 (Ruzaidi *et al.* 2005). Cocoa was used by ancient peoples as a medicinal plant for treating various disorders. Over 100 medicinal uses for cocoa have been documented in Europe and New Spain from the 16th to the early 20th century; it has been used to treat anaemia, mental fatigue, tuberculosis, fever, gout, kidney stones, and even poor sexual appetite (Dillinger *et al.* 2000). The cocoa bean contains a large number of phytochemicals, and physiologically active compounds have been reported. For example, Kim *et al.* (2011), reported that selected procyanidins present in cocoa inhibited tumorigenesis, tumour growth, and angiogenesis. Procyanidin-enriched cocoa seed extracts caused G2/M arrest and 70% growth inhibition in Caco-2 colon cancer cells. The consumption of cocoa or chocolate, which possesses high antioxidant activity, could be beneficial in decreasing damage caused by genotoxic and epigenetic carcinogens and inhibit the complex processes leading to cancer.



**Figure 1:** Cocoa (*T. cacao*) which contains high polyphenol content.

The use of bioactive compounds from *T. cacao* in the pharmaceutical and food industries indicates a need for the most appropriate and standardised methods for discovering such active components from plant materials. Ethnopharmacology-based phytochemical research is an effective approach for discovering novel active compounds that are potential anti-cancer drugs. The

*T. cacao* parts traditionally used for treating disease represent a source of chemical entities, but little information is available on their nature, except for that of the cocoa bean (Arlorio *et al.* 2005; Maskarinec 2009). Based on this viewpoint, scientists need to determine the best methods for natural product research, which include sample preparation, extraction, analytical techniques, bioassay-guided fractionation, isolation, and characterisation of plant bioactive metabolites as potential lead compounds in drug discovery. The analytical techniques employed are very important for purifying and identifying the active compound responsible for apoptotic activity, especially for agents that traditional use claims are anti-cancer. The efficiencies of conventional and nonconventional methods mostly depend on the critical input of parameters, understanding the nature of the plant matrix, and bioactive compound chemistry (Sasidharan *et al.* 2010; Azmir *et al.* 2013; Brusotti *et al.* 2014). This article reviews the literature concerning the important steps involved in discovering anti-cancer agents in the cocoa bean, i.e., extraction, bioassay evaluation, purification and identification, and assay of the mechanism of action by the apoptosis pathway.

## POTENTIAL ANTI-CANCER COMPOUNDS IN COCOA

Interest in the potential health-related benefits of antioxidant- and phytochemical-rich dark chocolate and cocoa has increased, and many studies have reported the health benefits of the bioactive compounds (Table 1) and chemical compositions of cocoa and cocoa products. Much of the proposed health-protective activity associated with cocoa and chocolate consumption has been attributed to flavonoids, polyphenols, and procyanidins. The major reported pharmacological activity in cocoa includes antioxidant effects (Othman *et al.* 2007), protection against cardiovascular disease (Corti *et al.* 2009), and anti-cancer effects (Maskarinec 2009). Many *in vitro* or experimental model studies have shown that flavonoids possess a wide range of biological activities related to anti-tumour effects, which include the inhibition of several kinases and transcription factors (TFs) (Kang *et al.* 2008). Flavonoids appear to be anti-proliferative, induce apoptosis, and inhibit angiogenesis; some are present in cocoa as monomers or procyanidins, have been studied *in vitro*, and are most likely to be effective as anti-cancer agents (Zhao *et al.* 1999; Eng *et al.* 2003; Shoji *et al.* 2005; Faria *et al.* 2006).

Nuclear factor- $\kappa$ B (NF- $\kappa$ B) is a TF involved in inflammation, cell proliferation, and oncogenic processes (Sun & Karin 2008). Activator protein-1 (AP-1) is a heterodimeric protein complex involved as a TF in apoptosis and cancer development, among other biological processes (Jeong *et al.* 2004). *In vitro* studies of cocoa epicatechin, catechin, and quercetin, as well as procyanidin and B-type dimeric procyanidin extracts, have shown that these compounds down-regulate NF- $\kappa$ B and AP-1 in cancer cell lines such as Hodgkin and Reed-Sternberg (HRS), Daudi, human acute monocytic leukaemia (THP-1), and Jurkat (Zhang *et al.* 2006; García-Mediavilla *et al.* 2007; Kang *et al.* 2008; Mackenzie *et al.* 2008). In contrast, the antioxidant effects of cocoa flavonoids delineate their putative beneficial action in controlling cell damage and tumour progression

(Martin *et al.* 2013). The cocoa procyanidins, epicatechin, and catechin exert powerful antioxidant effects (Miller *et al.* 2006; Jonfia-Essien *et al.* 2008; Belščak *et al.* 2009).

Previously, it was shown that a naturally occurring, cocoa-derived pentameric procyanidin (pentamer) caused G0/G1 phase cell cycle arrest in human breast cancer cells, and it was demonstrated that the pentamer selectively inhibited the proliferation of human breast cancer cells (MDA-MB-231, MDA-MB-436, MDA-MB-468, SKBR-3, MCF-7) and benzo(a)pyrene-immortalised 184A1N4 and 184B5 cells (Ramljak *et al.* 2005). The effects of cocoa powder and extracts with different amounts of flavonols and related procyanidin oligomers on human colonic cancer Caco-2 cell growth were also investigated: treatment with 50 mg/mL procyanidin-enriched (PE) extracts caused 70% growth inhibition with G2/M blockade, which might be an important target in the anti-proliferative effects of cocoa polyphenols (Carnésecchi *et al.* 2002). The phytochemical compounds present in cocoa, especially flavonoids, are involved in various pathways and are molecular targets for treating human cancer cells (Martin *et al.* 2013), which provides evidence that cocoa can be considered a potential anti-cancer agent and that it needs to be developed for treating cancer.

**Table 1:** *T. cacao* phenolic compounds and the cell line(s) tested.

Phenolic compound	Biological effect	Reference
Polymer procyanidins	Caco-2 (colon)	Erlejman <i>et al.</i> (2008)
Procyanidin B2	Caco-2 (colon), HL-60 (leukaemia)	Erlejman <i>et al.</i> (2008) and Sakano <i>et al.</i> (2005)
Epicatechin	Caco-2 (colon), SH-SY5Y (neuroblastoma), HepG2 (hepatoma), MCF-7 (breast)	Erlejman <i>et al.</i> (2008), Ramiro-Puig and Castell (2009), Granado-Serrano <i>et al.</i> (2010), and Rodgers and Grant (1998)
3'-O-methyl epicatechin	FEK4 (skin fibroblasts)	Basu-Modak <i>et al.</i> (2003)
Catechin	HepG2 (hepatoma), Caco-2 (colon), Int-407 (intestine)	Erlejman <i>et al.</i> (2008) and Cheng <i>et al.</i> (2013)

## EXTRACTION OF COCOA ACTIVE COMPOUNDS

Plants contain a wide range of active compounds such as lipids, phytochemicals, pharmaceuticals, flavours, fragrances, and pigments. Extraction is the first step in the utilisation of such bioactive compounds and thus is performed in virtually all studies of natural plant compounds. Prior to extraction, fresh plant materials are typically rinsed with water, dried at room temperature, and ground to obtain a powder. The common method for extracting anti-cancer compounds from plants is solvent extraction. As stated by Dai and Mumper (2010), solvent extractions are the most commonly used procedures for preparing extracts from plant materials due to their ease of use, efficiency, and wide applicability; the yield from

chemical extraction depends on the solvent type, of which there are varying polarities, and extraction time and temperature, sample-to-solvent ratio, and sample chemical composition and physical characteristics. Anti-cancer agent solubility is governed by the chemical nature of the plant sample and the polarity of the solvent system used. The simplest extraction technique is solvent soaking (Owens *et al.* 1998; Dai *et al.* 2009). Generally, organic solvents such as methanol, ethanol, acetone, ethyl acetate, and combinations thereof, often with different proportions of water, are used for extracting anti-cancer compounds from plant materials. Thus, the organic solvent selected can affect the amount and rate of crude extracts.

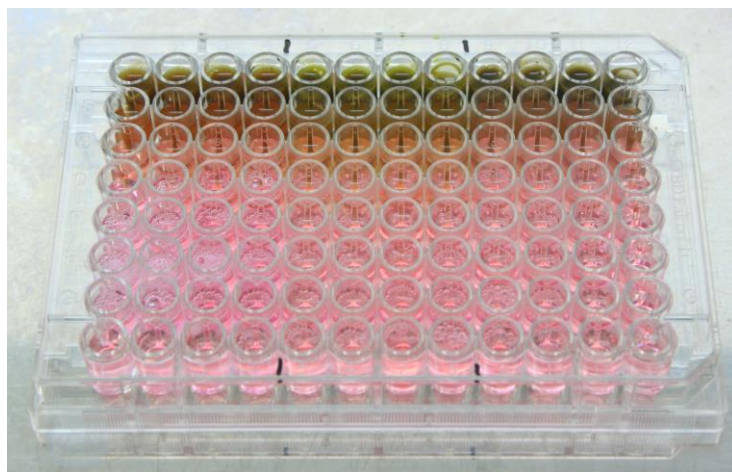
Given its high phenolic compound content, especially procyanidins and flavonols, *T. cacao* is recognised as a major dietary source of antioxidants (Tomas-Barberan *et al.* 2007); three main polyphenol groups have been identified in cocoa: catechins or flavan-3-ols (37%), proanthocyanidins (58%), and anthocyanins (4%) (Belščak *et al.* 2009). Polyphenols have garnered much interest recently due to their antioxidant capacity and possible benefits to human health such as anti-carcinogenic, anti-atherogenic, anti-ulcer, antithrombotic, anti-inflammatory, immune modulating, anti-microbial, vasodilatory, and analgesic effects (Hii *et al.* 2009). The extraction of phenolic compounds from plant materials is influenced by the chemical nature of the compounds, extraction method, sample size, time and storage conditions, and the presence of interfering substances such as proteins and carbohydrates (Koffi *et al.* 2010; García-Márquez *et al.* 2012). Yilmaz and Toledo (2006), reported that, compared to a single-compound solvent system, aqueous solutions of methanol, ethanol, and acetone dramatically improved polyphenol extraction. The relative recovery efficiency between solvents varies with different plant materials. The most commonly reported methods for polyphenol extraction are solvent maceration, such as Soxhlet extraction (Fig. 2), hot water extraction, alkaline extraction, resin-based extraction, enzyme-assisted extraction, gamma- and electron beam irradiation-based extraction, and supercritical fluid extraction. However, some of these methods can cause the loss of bioactive compounds due to the high temperatures used and long extraction times; additionally, irradiation can present a health risk if proper care is not taken (Liu *et al.* 2005; Dai & Mumper 2010).

Extraction and product recovery are the most crucial steps in evaluating target molecules from various plant parts (Fulzele & Satdive 2005). Presently, there is increasing demand for new extraction techniques with shorter extraction times, reduced organic solvent consumption, and increased pollution prevention (Wang & Weller 2006). Currently, several extraction methods such as sonication-, microwave-, and ultrasound-assisted extraction, supercritical fluid extraction, accelerated solvent extraction, pressurized solvent extraction, and pressurized liquid extraction can be applied for recovering polyphenols (Wang & Weller 2006; Wijngaard *et al.* 2012). Quiroz-Reyes *et al.* (2013), reported that ultrasonic radiation extraction yielded higher polyphenol content from both the husk and cotyledon of *T. cacao*, with high antioxidant activity. The shortcomings of the more established extraction methods have led to the use of new, sustainable, and innovative “green” techniques, e.g., microwave- and ultrasound-assisted extraction, that increase extraction efficiency, reduce time- and energy-

consuming procedures, and contribute to environmental preservation by reducing the use of water and solvents, fossil energy, and the generation of hazardous substances (Chemat *et al.* 2011). Lastly, the extraction process should provide the maximum yield of crude extract containing potential anti-cancer compounds, as well as extract of the highest quality (target compound concentrations and potential anti-cancer activities of the extracts).



**Figure 2:** Soxhlet used for conventional solvent extraction which is still relevant today.



**Figure 3:** Preparation of MTT assay in 96 well plate and cell viability measured using microplate reader.

## ACTIVITIES OF BIOASSAY-GUIDED COMPOUNDS

The bioassay is a very important aspect of screening for the anti-cancer activities of *T. cacao* plant part extracts, fractions, and pure compounds. The bioassay method used for other plants is compatible for use with the cocoa plant. Duarte *et al.* (2012), reported that active compound bioactivity establishes the potential application of natural products, and thus the design of the bioassay used is a crucial step in determining extract bioactivity for discovering target compounds based on said biological activity. It is essential that screening systems for natural products comprise a broad range of bioassays for exploring all possible anti-cancer activities. For bioassay screening, extract, fraction, and pure compound bioactivity can be screened *in vitro* and/or *in vivo*. *In vitro* testing can be performed at the cellular or molecular level. In this review, the discussed bioassay method for evaluating the anti-cancer activities of cocoa plant parts is the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay (Fig. 3).

The MTT assay was developed by Mosmann (1983) as a semi-automated colorimetric assay for the rapid assessment of proliferation and cytotoxicity in cell cultures. It is based on the mitochondrial reduction of the tetrazolium salt MTT to formazan, which can be quantified spectrophotometrically (Nikkhah *et al.* 1992). The MTT assay is one of the most convenient assays for estimating the viability of animal or bacterial cells and offers great advantages over conventional assays such as hemocytometer counting (Freimoser *et al.* 2000). MTT is a water-soluble yellow dye and can be reduced to water-insoluble purple formazan crystals by the dehydrogenase system in viable cells. Thus, the concentration of dissolved formazan crystals can be quantified spectrophotometrically and is directly proportional to the number of metabolically active cells (Wang *et al.* 2012). Dimethyl sulfoxide (DMSO) is considered one of the most suitable solvents for dissolution due to its high solubilising efficiency and low volatility (Wang *et al.* 2010). The MTT assay is also widely used to determine the cytotoxicities, effects on proliferation, and activities of potential medicinal agents based on cellular mitochondrial dehydrogenase activity. As an example, a study of the effects of methanolic non-edible plant extracts of *T. cacao* on several cancer cell lines showed that the MTT assay could be applied with confidence to evaluate the anti-proliferative activities of the extracts (Zainal *et al.* 2014a). Moreover, cocoa polyphenol-derived flavonols and procyanidins exhibit antioxidant and anti-tumour properties. Previous studies also reported using the MTT assay to investigate the cellular growth inhibitory effects of chemically-synthesised procyanidin [3-O-galloyl]-(-)-epicatechin-(4 $\beta$ ,8)-(+)-catechin-3-O-gallate (GECGC) in a variety of human cancer cell lines (Kim *et al.* 2008), the effects of cocoa extract polyphenols on MCF-7 cell viability (Oleaga *et al.* 2012), and the protective effects of a cocoa procyanidin fraction and procyanidin B2 (epicatechin-(4-8)-epicatechin) as the major cocoa polyphenol against hydrogen peroxide-induced apoptosis of rat pheochromocytoma PC12 cells (Cho *et al.* 2008). These studies indicate that the MTT assay is widely used in cell culture work involving cocoa extracts because it is simple, rapid, inexpensive, sensitive,



accurate, reproducible, requires little material for detection, and can be employed as an initial screening approach for plant extracts (Muraina *et al.* 2009).

The MTT assay can be modified to screen for anti-cancer activity in all plant extracts. Briefly, cancer cells ( $10^4$ – $10^5$ /well in 100  $\mu$ L of culture medium) are seeded in 96-well plates and treated with plant extracts for 24 h at 37°C in 5% CO<sub>2</sub>. Typically, the treated cancer cells are incubated with MTT solution (20  $\mu$ L, 5 mg/mL) at 37°C for 3–4 h and lysed with DMSO. The yellow MTT is reduced by succinic dehydrogenase in the mitochondria of viable cells to purple formazan crystals, and the absorbance (OD) is measured at 570 nm using a microplate reader. The results are recorded as the IC<sub>50</sub>, which is the sample concentration that inhibits 50% of cancer cell growth (Ibrahim *et al.* 2011; Mahavorasirikul *et al.* 2010; Sathiya & Muthuchelian 2010). As mentioned by Atjanasuppat *et al.* (2009), anti-cancer activity can be categorised according to IC<sub>50</sub> into four groups: active ( $\leq 20$  g/mL), moderately active ( $>20$ – $100$  g/mL), weakly active ( $>100$ – $1000$  g/mL), and inactive ( $>1000$  g/mL). The MTT assay has also been used to evaluate the anti-cancer activities of other plant extracts, such as *Centaurea jacea* against HeLa, MCF-7, and A431 cells (Forgo *et al.* 2012), *Typhonium flagelliforme* against NCI-H23 and HS578T cells (Lai *et al.* 2010), *Platycodon grandiflorum* A. against HT-29, HRT-18, and HepG2 cells (Lee *et al.* 2004), South African plants against MCF-7, TK10, and UACC62 cells (Fouche *et al.* 2008), and *Tinospora crispa* against MCF-7, MDA-MB-231, and HeLa cells (Ibrahim *et al.* 2011). However, the assay cannot distinguish between cytostatic and cytotoxic effects, does not quantify individual cell numbers, and is least efficient when performed in a medium that has supported cellular growth for several days (Supino 1995). Other than the MTT assay, there are few tetrazolium salt reduction assays for measuring viable cell numbers.

Mosmann (1983), reported that the most frequently used tetrazolium salts are MTT, 2,3-bis-(2-methoxy-4-nitro-5-sulfophenyl)-2H-tetrazolium-5-carboxanilide (XTT), and 4-[3-(4-iodophenyl)-2-(4-nitrophenyl)-2H-5-tetrazolio]-1,3-benzene disulfonate water-soluble tetrazolium salt (WST-1). Despite their wide use and applicability, researchers using these assays may encounter compatibility issues depending on the study objectives. For example, compared to XTT and MTT, WST-1 is more stable, has a broader linear range, and enables more rapid colour development. MTT can be reduced by nicotinamide adenine dinucleotide phosphate (NADPH), flavin adenine dinucleotide (FADH), and nicotinamide adenine dinucleotide (NADH) but not by cytochromes. Tetrazolium salts are generally cytotoxic because the formazan crystals produced from the salt reduction must be solubilised with DMSO or hydrochloric acid/isopropanol, which destroys the cells being studied; therefore, time course experiments cannot be performed. However, there are other assays for determining cell viability, such as intracellular adenosine triphosphate (ATP)-based, deoxynucleic acid (DNA)-based, and Alamar Blue assays. The ATP-based method is highly sensitive, reproducible, and simple for evaluating cell viability and proliferation. The amount of ATP present in the cells is proportional to the number of viable cells in culture. Similar results can be obtained using the DNA-based method, which is based on the measurement of cellular DNA to indicate the relative cell numbers, as cellular

DNA content is highly regulated (Crouch *et al.* 1993; Jones *et al.* 2001; Mueller *et al.* 2004; Wang *et al.* 2010). The active ingredient in the Alamar Blue assay is resazurin (International Union of Pure and Applied Chemistry [IUPAC] name: 7-hydroxy-10-oxidophenoxazin-10-ium-3-one, also known as diazo-resorcinol, azoresorcin, resazoin, or resazurine); it enables accurate time course measurements, has high sensitivity and linearity, involves no cell lysis, is water-soluble, ideal for use with post-measurement functional assays, flexible (can be used with different cell models), scalable, can be used with fluorescence- and/or absorbance-based instrumentation platforms, and is non-toxic and non-radioactive, meaning it is safe for the user and the environment (O'Brien *et al.* 2000; Rampersad 2012).

## PURIFICATION OF ACTIVE COMPOUNDS

Following bioassay screening, the crude extracts of cocoa plant parts with potential anti-cancer activities are further investigated to identify the chemical structures of the potential anti-cancer agents. The first step in purifying and characterising the potential anti-cancer agents is fractionation and purification, a multi-step procedure. Fresh or dry samples are ground into powder, followed by (i) organic solvent, water, and CO<sub>2</sub> extraction, (ii) solvent partitioning to remove less polar and/or more polar compounds, (iii) fractionation (flash chromatography, counter-current chromatography, or low-pressure column chromatography [CC] on silica or alumina), and (iv) final purification by thin-layer chromatography (TLC) and/or high-performance liquid chromatography (HPLC) (Fig. 4) for removing more and less polar compounds (Dinan *et al.* 2001). A plant crude extract contains a complicated mix of several bioactive compounds and potential anti-cancer agents. Therefore, it is often necessary to initially fractionate the crude extract into various discrete fractions containing groups of compounds with similar polarities or molecular sizes using CC, prep-HPLC, and solid-phase extraction (SPE). However, the initial fractionation should not generate too many fractions from any crude extract, as the target compound may be divided between these fractions, such that only low concentrations of potential anti-cancer agents are produced, which might evade detection or not exhibit detectable anti-cancer activity in bioassay-guided fractionation (Sarker & Nahar 2012). The most important factor to be considered before designing an isolation protocol is the nature of the target compound present in the crude extracts or fractions. The general features of the molecule that can aid isolation process design include solubility (hydrophobicity or hydrophilicity), acid-base properties, charge, stability, and molecular size. It is easy to obtain information from the literature on the chromatographic behaviour of the target compound if a known compound is isolated from the same or a new source, and the most appropriate method can be selected. However, for as yet unknown reasons, it is more difficult to design an isolation protocol for a crude extract. For discovering unknown anti-cancer agents, it is advisable to perform phytochemical testing for the presence of compounds such as phenolics, steroids, alkaloids, and flavonoids (Sarker *et al.* 2005).



**Figure 4:** The main components of a modern HPLC system.

Subsequently, the isolated potential anti-cancer agents are identified or characterised by conclusive structure elucidation methods. However, elucidating the structures of natural products is generally time-consuming and sometimes can be a bottleneck in anti-cancer research. With established anti-cancer agents, this may not pose a significant difficulty, but it can certainly be challenging if the compounds are new entities. Many spectroscopic methods can be used to obtain valuable information regarding the chemical structures of compounds, but interpreting these spectra requires specialised spectroscopic knowledge, structure elucidation skills, sound understanding of natural products chemistry, and above all, a great deal of patience (Duarte *et al.* 2012). As mentioned previously (Salim *et al.* 2008; Sarker & Nahar 2012), past drug discovery from plant bioactive compounds is time-consuming, and depending on the complexity of the structures, identifying the structures of active compounds from an extract could take weeks, months, or even years. Currently, bioassay-guided fractionation has become significantly faster due to improvements in instrumentation such as ultraviolet–visible spectroscopy (UV–vis), which provides information on chromophores present in the molecule, infrared spectroscopy (IR), which provides information on different functional groups, and mass spectrometry (MS), which yields information on molecular mass, molecular formula, and fragmentation patterns. The most commonly used MS methods are electron impact MS (EIMS), chemical ionisation MS (CIMS), electrospray ionisation MS (ESIMS), fast atom bombardment MS (FABMS), and matrix-assisted laser desorption ionisation (MALDI). Nuclear magnetic resonance (NMR) yields information on the numbers and types of protons and carbons (and other elements, such as nitrogen and fluorine) present in the molecule, and the

relationships among these atoms are categorised using one- and two-dimensional NMR techniques.

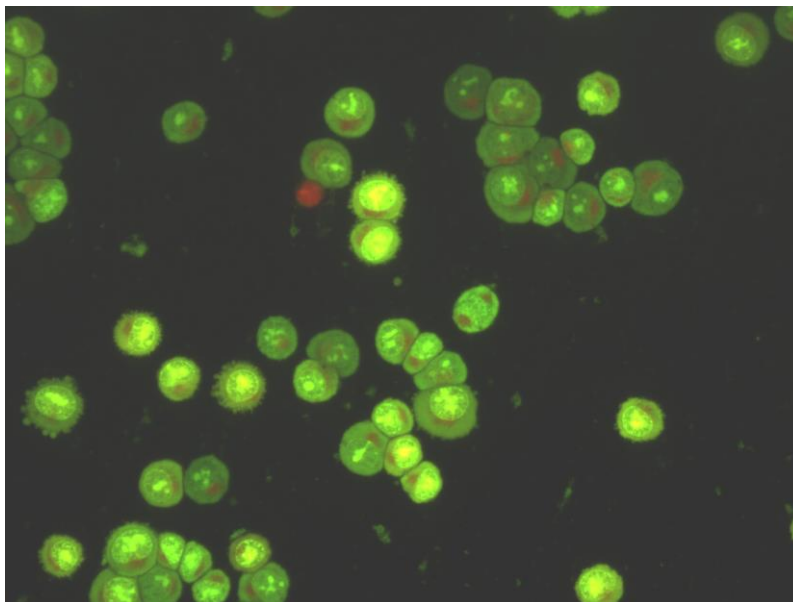
Cocoa beans are a rich source of flavonoids, especially epicatechin, and catechin and its polymer forms, the monomer of which is procyanidin. Different plant varieties and parts yield different compounds (Jayasekera *et al.* 2011). As plant extracts usually occur as a combination of bioactive compounds or phytochemicals with different polarities, their separation and purification remains a large challenge for bioactive compound identification and characterisation. The common practices in bioactive compound purification and identification involve separation techniques such as TLC, CC, and HPLC, which are used to obtain pure compounds for identification (Martin & Guiochon 2005; Sticher 2008). The purification, identification, and structure elucidation methods for polyphenols in cocoa components are the focus in analytical methods that emphasise HPLC, the typical method of choice due to its high resolution, efficiency, and reproducibility and relatively short analysis time, which is not limited by sample volatility. Moreover, HPLC can be coupled to a variety of detectors such as UV-vis, photodiode array (PDA), fluorescence, electrochemical (ECD), and MS. However, it is worth considering TLC as a screening method and capillary electrophoresis (CE) as a promising tool (Wollgast & Anklam 2000). As reported previously (Calderón *et al.* 2009), rapid methods are needed to evaluate and compare food products for their antioxidant benefits, and new assays based on liquid chromatography-MS (LC-MS) have been developed for identifying and quantitatively analysing antioxidants in complex natural product samples such as food extracts. Assay analysis of cocoa powder methanolic extracts determined that procyanidins were the most potent antioxidant species. These species were identified using LC-MS, LC-MS-MS, accurate mass measurement, and comparison with reference standards. Catechin and epicatechin were the most abundant antioxidants, followed by their dimers and trimers. The new LC-MS assay facilitates the rapid identification and determination of the relative antioxidant activities of individual antioxidant species in complex compounds in cocoa. Gas chromatography-MS (GC-MS) also can be used to identify potential anti-cancer compounds from non-edible parts of *T. cacao* (Zainal *et al.* 2014b). NMR identification of new or unknown compounds is also necessary, as reported previously (Alemanno *et al.* 2003), in which the three most abundant new polyphenolic compounds from cocoa, i.e., N-trans-caffeoyl-L-DOPA, N-trans-*p*-coumaroyl-L-tyrosine, and N-trans-caffeoyl-L-tyrosine, were isolated and characterised using <sup>1</sup>H- and <sup>13</sup>C-NMR.

## EVALUATION OF APOPTOTIC EFFECTS OF COCOA ACTIVE COMPOUNDS

Purified potential anti-cancer compounds from *T. cacao* are evaluated based on their apoptotic effects. There are many articles examining the induction of apoptosis in cancer cells by cocoa bean extracts and other medicinal plant extracts (Maskarinec 2009; Martin *et al.* 2013). Apoptosis, an active physiological process involved in the cellular self-destruction of unwanted cells, is disrupted in cancer cells and is characterised by distinct morphologic changes, including cell

shrinkage, membrane blebbing, chromatin condensation, DNA fragmentation, and apoptotic body formation (Shafi *et al.* 2009). Therapeutic applications of apoptosis are considered a good model for evaluating potential anti-cancer agents from cocoa bean extracts and represent a very important method for studying the apoptotic activity induced by anti-cancer agents. This review discusses the *in vitro* apoptotic activities of cocoa bean polyphenol compounds. As an example, polyphenols can affect the overall process of carcinogenesis through several mechanisms (D'Archivio *et al.* 2008). In particular, polyphenols are involved in counteracting the occurrence of oxidative stress, thus contributing to the prevention of cancer onset and development. Furthermore, polyphenol modulation of oxidative stress in cancer cells affects signal transduction, activation of redox-sensitive TFs, and the expression of specific genes that influence cell proliferation and apoptosis (Fig. 5). In addition, the evidence indicates that polyphenols can directly modulate different parts of the apoptotic process and/or the expression of regulatory proteins, such as cytochrome c release with subsequent caspase-9 and caspase-3 activation, increased caspase-8 and truncated Bid (t-Bid) levels, Bcl-2 and Bcl-XL downregulation, enhanced Bax and Bak expression, and NF- $\kappa$ B modulation (Cho *et al.* 2008; D'Archivio *et al.* 2008; Rodríguez-Ramiro *et al.* 2011).

Brisson (2007), also mentioned that cell death induced by the epigallocatechin-3-gallate (EGCG) group of polyphenolic compounds involves the stimulation of diverse protein kinases and the modulation of cell survival/cell death genes. Changes such as increased p53 and Bax, decreased Bcl-2 and Bcl-XL, and caspase-9 activation suggest that these molecules interfere with the mitochondrial pathway, leading to apoptosis. These events suggest an effect on the mitochondrial pathway of apoptosis. In addition, a study of pentameric procyanidin from *T. cacao*, which inhibited breast cancer cells, showed that the mitochondrial effects caused by the pentamer trigger growth arrest or apoptotic or nonapoptotic cell death processes. Studies using the novel mitochondriotoxic small molecule F16 have suggested that compounds causing mitochondrial depolarisation inhibit the tumour growth of breast cancer cells through G1 arrest, apoptosis, or necrosis, depending on the genetic background of the cell (Ramljak *et al.* 2005). Typically, the induction of apoptosis is determined using the terminal deoxynucleotidyl transferase dUTP nick end labelling (TUNEL) assay (Gunadharini *et al.* 2011), cell cycle analysis (Arlorio *et al.* 2009), DNA fragmentation (Machana *et al.* 2012), western blotting (Hsu *et al.* 2011), mitochondrial membrane potential assay (Ramljak *et al.* 2005), or caspase-3 activity assay (Alshatwi *et al.* 2011).



**Figure 5:** Apoptosis inductions in treated breast cancer cell line by cocoa plant part extract viewed under fluorescence microscope.

## CONCLUSION

Cocoa is a high-nutritional value food with bioactive compounds that have been demonstrated to be effective in some physiological and pathophysiological processes, and previous studies have suggested the efficacy of cocoa as a potential anti-proliferative agent. Screening of new anti-cancer agents from cocoa plant parts, especially cocoa beans, depends on the quality of sample collection, storage, extraction, and purification. There is no specific technique for discovering the constituents of the complex mixture present in *T. cacao* plant part extracts. However, broad separation can be achieved by fractionation with organic solvents and chromatographic techniques. An appropriate protocol for extraction, bioassay-guided fractionation, and purification can be designed only when the targeted compound has been determined and more information has been obtained on the chemical and physical properties of the compounds. For unknown active compounds, trial-and-error extraction and purification are performed. To reduce the cost, time, and solvents used, techniques based on green analytical chemistry should be used for extracting and purifying potential anti-cancer agents from *T. cacao*.

NMR, LC-MS and GC-MS structural characterisation play important roles in anti-cancer agent discovery, as more sensitive and faster structural analysis methods expedite such discoveries. These techniques also yield valuable preliminary information about the contents and nature of potential anti-cancer compounds, which is very useful when there are numerous samples to be

processed, avoiding unnecessary isolation of compounds. The MTT assay produces highly reproducible results in the assessment of cell culture viability and is a valid, inexpensive, rapid, and simple system that is potentially useful for in vitro assays with human cancer cell lines. Several studies have indicated that plant anti-cancer agents act either through interaction with the cell cycle or by activating an apoptotic pathway. As multiple mechanisms can initiate apoptosis, the targets of plant substances could be diverse and may be dependent on the cellular context. Several reviews have indicated the diversity and number of putative molecular targets. This is important for characterising the cellular events leading to apoptosis to define the strategic use of potential anti-cancer agents in cocoa for treating human cancers.

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## REFERENCES

- Alemanno L, Ramos T, Gargadene A, Andary C and Ferriere N. (2003). Localization and identification of phenolic compounds in *Theobroma cacao* L. somatic embryogenesis. *Annals of Botany* 92(4): 613–23. doi:10.1093/aob/mcg177
- Alshatwi A, Shafi G, Hasan T, Al-Hazzani A, Alsaif M, Alfawaz M, Lei K Y and Munshi A. (2011). Apoptosis-mediated inhibition of human breast cancer cell proliferation by lemon citrus extract. *Asian Pacific Journal of Cancer Prevention* 12(6): 1555–1559.
- Arlorio M, Bottini C, Travaglia F, Locatelli, M, Bordiga M, Coisson J D, Martelli A and Tessitore L. (2009). Protective activity of *Theobroma cacao* L. phenolic extract on AML12 and MLP29 liver cells by preventing apoptosis and inducing autophagy. *Journal of Agricultural and Food Chemistry* 57(22): 10612–10618. doi:10.1021/jf902419t
- Arlorio M, Coisson J D, Travaglia F, Varsaldi F, Miglio G, Lombardi G and Martelli A. (2005). Antioxidant and biological activity of phenolic pigments from *Theobroma cacao* hulls extracted with supercritical CO<sub>2</sub>. *Food Research International* 38(8–9): 1009–1014. doi:10.1016/j.foodres.2005.03.012
- Atjanasuppat K, Wongkham W, Meepowpan P, Kittakoop P, Sobhon P, Bartlett A and Whitfield P J. (2009). In vitro screening for anthelmintic and antitumour activity of ethnomedicinal plants from Thailand. *Journal of Ethnopharmacology* 123(3): 475–482. doi:10.1016/j.jep.2009.03.010
- Azmir J, Zaidul I S M, Rahman M M, Sharif K M, Mohamed A, Sahena F, Jahurul M H A, Ghafoor K, Norulaini N A N and Omar A K M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *Journal of Food Engineering* 117(4): 426–436. doi:10.1016/j.jfoodeng.2013.01.014

- Basu-Modak S, Gordon M J, Dobson L H, Spencer J P E, Rice-Evans C and Tyrrell R M. (2003). Epicatechin and its methylated metabolite attenuate UVA-induced oxidative damage to human skin fibroblasts. *Free Radical Biology and Medicine* 35(8): 910–921. doi:10.1016/S0891-5849(03)00436-2
- Belščak A, Komes D, Horžić D, Ganić K K and Karlović D. (2009). Comparative study of commercially available cocoa products in terms of their bioactive composition. *Food Research International* 42(5–6): 707–716. doi:10.1016/j.foodres. 2009. 02.018
- Bennett L L, Rojas S and Seefeldt T. (2012). Role of antioxidants in the prevention of cancer. *Journal of Experimental & Clinical Medicine* 4(4): 215–222. doi:10.1016/j.jecm.2012.06.001
- Bhattacharjee R and Kumar P L. (2007). Cacao. In C Kole (ed.). *Genome mapping and molecular breeding*, vol. 7. New York: Springer, 127–142.
- Brisson L F. (2007). Apoptosis and plant-derived pharmaceuticals. In K G Ramawat and J Merillon (eds.). *Bioactive molecules and medicinal plants*. Berlin: Springer, 317–324.
- Brusotti G, Cesari I, Dentamaro A, Caccialanz, G and Massolini G. (2014). Isolation and characterization of bioactive compounds from plant resources: The role of analysis in the ethnopharmacological approach. *Journal of Pharmaceutical and Biomedical Analysis* 87: 218–28. doi:10.1016/j.jpba.2013.03.007
- Calderón A I, Wright B J, Hurst W J and van Breemen R B. (2009). Screening antioxidants using LC-MS: Case study with cocoa. *Journal of Agricultural and Food Chemistry* 57(13): 5693–5699. doi:10.1021/jf9014203
- Carnésecchi S, Schneider Y, Lazarus S A, Coehlo D, Gossé F and Raul F. (2002). Flavanols and procyanidins of cocoa and chocolate inhibit growth and polyamine biosynthesis of human colonic cancer cells. *Cancer Letters* 175(2): 147–155. doi:S0304383501007315[pii]
- Chemat F, Zill-e-Huma and Khan M K. (2011). Applications of ultrasound in food technology: Processing, preservation and extraction. *Ultrasonics Sonochemistry* 18(4): 813–835. doi:10.1016/j.ultsonch.2010.11.023
- Cheng Y-T, Wu C-H, Ho C-Y and Yen G-C. (2013). Catechin protects against ketoprofen-induced oxidative damage of the gastric mucosa by up-regulating Nrf2 in vitro and in vivo. *The Journal of Nutritional Biochemistry* 24(2): 475–483. doi:10.1016/j.jnutbio.2012.01.010
- Cho E S, Lee K W and Lee H J. (2008). Cocoa procyanidins protect PC12 cells from hydrogen-peroxide-induced apoptosis by inhibiting activation of p38 MAPK and JNK. *Mutation Research* 640(1–2): 123–130. doi:10.1016/j.mrfmmm.2007.12.012
- Corti R, Flammer A J, Hollenberg N K and Lüscher T F. (2009). Cocoa and cardiovascular health. *Circulation* 119(10): 1433–1441. doi:10.1161/CIRCULATIONAHA.108.827022
- Cragg G M and Newman D J. (2013). Natural products: A continuing source of novel drug leads. *Biochimica et Biophysica Acta* 1830(6): 3670–3695. doi:10.1016/j.bbagen.2013.02.008
- \_\_\_\_\_. (2005). International collaboration in drug discovery and development from natural sources. *Pure and Applied Chemistry* 77(11): 1923–1942. doi:10.1351/pac200577111923
- Cragg G M, Newman D J and Snader K M. (1997). Natural products in drug discovery and development. *Journal of Natural Products* 60(1): 52–60. doi:10.1021/np9604893
- Crouch S P M, Kozlowski R, Slater K J and Fletcher J. (1993). The use of ATP bioluminescence as a measure of cell proliferation and cytotoxicity. *Journal of Immunological Methods* 160(1): 81–88. doi:10.1016/0022-1759(93)90011-U



- D'Archivio M, Santangelo C, Scazzocchio B, Vari R, Filesi C, Masella R and Giovannini C. (2008). Modulatory effects of polyphenols on apoptosis induction: Relevance for cancer prevention. *International Journal of Molecular Sciences* 9(3): 213–228. doi:10.3390/ijms9030213
- Dai J, Gupte A, Gates L and Mumper R J. (2009). A comprehensive study of anthocyanin-containing extracts from selected blackberry cultivars: Extraction methods, stability, anticancer properties and mechanisms. *Food and Chemical Toxicology* 47(4): 837–847. doi:10.1016/j.fct.2009.01.016
- Dai J and Mumper R J. (2010). Plant phenolics: Extraction, analysis and their antioxidant and anticancer properties. *Molecules* 15(10): 7313–7352. doi:10.3390/molecules15107313
- Dillinger T L, Barriga P, Escárcega S, Jimenez M, Salazar Lowe D and Grivetti L E. (2000). Food of the gods: cure for humanity? A cultural history of the medicinal and ritual use of chocolate. *The Journal of Nutrition* 130(8S Suppl): 2057S–2072S.
- Dinan L, Harmatha J and Lafont R. (2001). Chromatographic procedures for the isolation of plant steroids. *Journal of Chromatography A* 935(1–2): 105–123. doi:10.1016/S0021-9673(01)00992-X
- Duarte K, Rocha-Santos T A P, Freitas A C and Duarte A C. (2012). Analytical techniques for discovery of bioactive compounds from marine fungi. *TrAC - Trends in Analytical Chemistry* 34(1): 97–110. doi:10.1016/j.trac.2011.10.014
- Eng E T, Ye J, Williams D, Phung S, Moore R E, Young M K, Gruntmanis U, Braunstein G and Chen S. (2003). Suppression of estrogen biosynthesis by procyanidin dimers in red wine and grape seeds. *Cancer Research* 63(23): 8516–8522.
- Erlejman A G, Jagers G, Fraga C G and Oteiza P I. (2008). TNF alpha-induced NF-kappaB activation and cell oxidant production are modulated by hexameric procyanidins in Caco-2 cells. *Archives of Biochemistry and Biophysics* 476(2): 186–195. doi:10.1016/j.abb.2008.01.024
- Faria A, Calhau C, de Freitas V and Mateus N. (2006). Procyanidins as antioxidants and tumor cell growth modulators. *Journal of Agricultural and Food Chemistry* 54(6): 2392–2497. doi:10.1021/jf0526487
- Forgo P, Zupkó I, Molnár J, Vasas A, Dombi G and Hohmann J. (2012). Bioactivity-guided isolation of antiproliferative compounds from *Centaurea jacea* L. *Fitoterapia* 83(5): 921–925. doi:10.1016/j.fitote.2012.04.006
- Fouche G, Cragg G M, Pillay P, Kolesnikova N, Maharaj V J and Senabe J. (2008). In vitro anticancer screening of South African plants. *Journal of Ethnopharmacology* 119(3): 455–461. doi:10.1016/j.jep.2008.07.005
- Freimoser F M, Grundschober A, Aebi M and Tuor U. (2000). In vitro cultivation of the entomopathogenic fungus *Entomophthora thripidum*: Isolation, growth requirements, and sporulation. *Mycologia* 92(2): 208–215. doi:10.2307/3761552
- Fulzele D P and Satdive R K. (2005). Comparison of techniques for the extraction of the anti-cancer drug camptothecin from *Nothapodytes foetida*. *Journal of Chromatography A* 1063(1–2): 9–13. doi:10.1016/j.chroma.2004.11.020
- García-Maquéz E, Román-Guerrero A, Peñez-Alonso C, Cruz-Sosa F, Jiménez-Alvarado R and Vernon-Carter E J. (2012). Effect of solvent-temperature extraction conditions on the initial antioxidant activity and total phenolic content of Muitle extracts and their decay upon storage at different pH. *Revista Mexicana de Ingeniería Química* 11(1): 1–10.

- García-Mediavilla V, Crespo I, Collado P S, Esteller A, Sánchez-Campos S, Tuñón M J and González-Gallego J. (2007). The anti-inflammatory flavones quercetin and kaempferol cause inhibition of inducible nitric oxide synthase, cyclooxygenase-2 and reactive C-protein, and down-regulation of the nuclear factor kappaB pathway in Chang Liver cells. *European Journal of Pharmacology* 557(2–3): 221–9. doi:10.1016/j.ejphar.2006.11.014
- Granado-Serrano A B, Martín M A, Haegeman G, Goya L, Bravo L and Ramos S. (2010). Epicatechin induces NF-kappaB, activator protein-1 (AP-1) and nuclear transcription factor erythroid 2p45-related factor-2 (Nrf2) via phosphatidylinositol-3-kinase/protein kinase B (PI3K/AKT) and extracellular regulated kinase (ERK) signalling in HepG2 ce. *The British Journal of Nutrition* 103(2): 168–179. doi:10.1017/S0007114509991747
- Grassi D and Ferri C. (2012). Chocolate and health. In A Conti, R Paoletti, A Poli and F Visioli (eds.). *Chocolate and health*. Milan: Springer, 115–125.
- Gunadharini D N, Elumalai P, Arunkumar R, Senthilkumar K and Arunakaran J. (2011). Induction of apoptosis and inhibition of PI3K/Akt pathway in PC-3 and LNCaP prostate cancer cells by ethanolic neem leaf extract. *Journal of Ethnopharmacology* 134(3): 644–650. doi:10.1016/j.jep.2011.01.015
- Hii C L, Law C L, Suzannah S, Misnawi and Cloke M. (2009). Polyphenols in cocoa (*Theobroma cacao* L.). *Asian Journal of Food and Agro-Industry* 2(4): 702–722.
- Hsu H-F, Huang K-H, Lu K-J, Chiou S-J, Yen J-H, Chang C-C and Houng J-Y. (2011). *Typhonium blumei* extract inhibits proliferation of human lung adenocarcinoma A549 cells via induction of cell cycle arrest and apoptosis. *Journal of Ethnopharmacology* 135(2): 492–500. doi:10.1016/j.jep.2011.03.048
- Ibrahim M, Wan Nor l'zzah W, Narimah A, Nurul Asyikin Z, Siti Nur Shafinas S and Froemming G. (2011). Anti-proliferative and antioxidant effects of *Tinospora crispa* (Batawali). *Biomedical Research* 22(1): 57–62.
- Jayasekera S, Molan A L, Garg M and Moughan P J. (2011). Variation in antioxidant potential and total polyphenol content of fresh and fully-fermented Sri Lankan tea. *Food Chemistry* 125(2): 536–541. doi:10.1016/j.foodchem.2010.09.045
- Jeong W-S, Kim I-W, Hu R and Kong A-N T. (2004). Modulation of AP-1 by natural chemopreventive compounds in human colon HT-29 cancer cell line. *Pharmaceutical Research* 21(4): 649–660.
- Jones L J, Gray M, Yue S T, Haugland R P and Singer V L. (2001). Sensitive determination of cell number using the CyQUANT® cell proliferation assay. *Journal of Immunological Methods* 254(1–2): 85–98. doi:10.1016/S0022-1759(01)00404-5
- Jonfia-Essien W A, West G, Alderson P G and Tucker G. (2008). Phenolic content and antioxidant capacity of hybrid variety cocoa beans. *Food Chemistry* 108(3): 1155–1159. doi:10.1016/j.foodchem.2007.12.001
- Kang N J, Lee K W, Lee D E, Rogozin E A, Bode A M, Lee H J and Dong Z. (2008). Cocoa procyanidins suppress transformation by inhibiting mitogen-activated protein kinase kinase. *The Journal of Biological Chemistry* 283(30): 20664–20673. doi:10.1074/jbc.M800263200
- Kim J, Lee K W and Lee H J. (2011). Cocoa (*Theobroma cacao*) seeds and phytochemicals in human health. In V Preedy, E E Vatson and V B Patel (eds.). *Nuts and seeds in health and disease prevention*. London: Academic Press, 351–360.
- Kim M, Wu X, Song I, Fu M, Chang S-H, Lisanti M P and Pestell R. (2008). Selective cytotoxicity of synthesized procyanidin 3-O-galloylepicatechin-4b, 8-3-O-galloylcatechin to human cancer cells. *Cell Cycle* 7(11): 1648–1657.

- Kinghorn A D. (2000). Plant secondary metabolites as potential anticancer agents and cancer chemopreventives. *Molecules* 5(3): 285–288.
- Kinghorn A D, Farnsworth N R, Soejarto D D, Cordell G A, Pezzuto J M, Udeani G O, Wani M C *et al.* (1999). Novel strategies for the discovery of plant-derived anticancer agents. *Pure and Applied Chemistry* 71(9): 1611–1618. doi:10.1351/pac199971091611
- Koffi E, Sea T, Dodehe Y and Soro S. (2010). Effect of solvent type on extraction of polyphenols from twenty three Ivorian plants. *Journal of Animal & Plant Sciences* 5(3): 550–558.
- Lai C-S, Mas R H M H, Nair N K, Mansor S M and Navaratnam V. (2010). Chemical constituents and in vitro anticancer activity of *Typhonium flagelliforme* (Araceae). *Journal of Ethnopharmacology* 127(2): 486–494. doi:10.1016/j.jep.2009.10.009
- Lee J-Y, Hwang W-I and Lim S. (2004). Antioxidant and anticancer activities of organic extracts from *Platycodon grandiflorum* A. De Candolle roots. *Journal of Ethnopharmacology* 93(2–3): 409–415. doi:10.1016/j.jep.2004.04.017
- Liu C-T, Wu C-Y, Weng Y-M and Tseng C-Y. (2005). Ultrasound-assisted extraction methodology as a tool to improve the antioxidant properties of herbal drug Xiao-chia-hu-tang. *Journal of Ethnopharmacology* 99(2): 293–300. doi:10.1016/j.jep.2005.02.018
- Machana S, Weerapreeyakul N and Barusrux S. (2012). Anticancer effect of the extracts from *Polyalthia evecata* against human hepatoma cell line (HepG2). *Asian Pacific Journal of Tropical Biomedicine* 2(5): 368–374. doi:10.1016/S2221-1691(12)60058-6
- Mackenzie G G, Adamo, A M, Decker N P and Oteiza P I. (2008). Dimeric procyanidin B2 inhibits constitutively active NF-kappaB in Hodgkin's lymphoma cells independently of the presence of IkappaB mutations. *Biochemical Pharmacology* 75(7): 1461–1471. doi:10.1016/j.bcp.2007.12.013
- Mahavorasirikul W, Viyanant V, Chaijaroenkul W, Itharat A and Na-Bangchang K. (2010). Cytotoxic activity of Thai medicinal plants against human cholangiocarcinoma, laryngeal and hepatocarcinoma cells in vitro. *BMC Complementary and Alternative Medicine* 10(55): 1–8. doi:10.1186/1472-6882-10-55
- Martin M A, Goya L and Ramos S. (2013). Potential for preventive effects of cocoa and cocoa polyphenols in cancer. *Food and Chemical Toxicology* 56: 336–351. doi:10.1016/j.fct.2013.02.020
- Martin M and Guiochon G. (2005). Effects of high pressure in liquid chromatography. *Journal of Chromatography A* 1090(1–2): 16–38. doi:10.1016/j.chroma.2005.06.005
- Maskarinec G. (2009). Cancer protective properties of cocoa: A review of the epidemiologic evidence. *Nutrition and Cancer* 61(5): 573–579. doi:10.1080/01635580902825662
- Miller K B, Stuart D, Smith N L, Lee C Y, McHale N L, Flanagan J, Ou B and Hurst W J. (2006). Antioxidant activity and polyphenol and procyanidin contents of selected commercially available cocoa-containing and chocolate products in the United States. *Journal of Agricultural and Food Chemistry* 54(11): 4062–4068. doi:10.1021/jf060290o
- Mosmann T. (1983). Rapid colorimetric assay for cellular growth and survival: Application to proliferation and cytotoxicity assays. *Journal of Immunological Methods* 65(1–2): 55–63. doi:10.1016/0022-1759(83)90303-4
- Mueller H, Kassack M U and Wiese M. (2004). Comparison of the usefulness of the MTT, ATP, and calcein assays to predict the potency of cytotoxic agents in various human cancer cell lines. *Journal of Biomolecular Screening* 9(6): 506–515. doi:10.1177/1087057104265386

- Muraina I A, Suleiman M M and Eloff J N. (2009). Can MTT be used to quantify the antioxidant activity of plant extracts? *Phytomedicine: International Journal of Phytotherapy and Phytopharmacology* 16(6–7): 665–668. doi:10.1016/j.phymed.2008.11.005
- National Cancer Registry. (2011). Malaysia cancer statistics data and figure 2007. In Z A Omar and N S I Tamin (eds.). *National cancer registry report*. Putrajaya: Ministry of Health, Malaysia, 1–126.
- Nikkhah G, Tonn J C, Hoffmann O, Kraemer H P, Darling J L, Schachenmayr W and Schönmayr R. (1992). The MTT assay for chemosensitivity testing of human tumors of the central nervous system. Part II: Evaluation of patient- and drug-specific variables. *Journal of Neuro-Oncology* 13(1): 13–24.
- O'Brien J, Wilson I, Orton T and Pognan F. (2000). Investigation of the Alamar Blue (resazurin) fluorescent dye for the assessment of mammalian cell cytotoxicity. *European Journal of Biochemistry* 267(17): 5421–5426. doi:10.1046/j.1432-1327.2000.01606.x
- Oleaga C, García M, Solé A, Ciudad C J, Izquierdo-Pulido M and Noé V. (2012). CYP1A1 is overexpressed upon incubation of breast cancer cells with a polyphenolic cocoa extract. *European Journal of Nutrition* 51(4): 465–76. doi:10.1007/s00394-011-0231-2
- Othman A, Ismail A, Abdul Ghani N and Adenan I. (2007). Antioxidant capacity and phenolic content of cocoa beans. *Food Chemistry* 100(4): 1523–1530. doi:10.1016/j.foodchem.2005.12.021
- Owens M K, Straka E J, Carroll C J and Taylor C A. (1998). Technical note: A comparison of techniques for extracting monoterpenoids from *Juniperus* (Cupressaceae) species. *Journal of Range Management* 51(5): 540–544.
- Plankar M, Jerman I and Krašovec R. (2011). On the origin of cancer: Can we ignore coherence? *Progress in Biophysics and Molecular Biology* 106(2): 380–90. doi:10.1016/j.pbiomolbio.2011.04.001
- Pujol M, Gavilondo J, Ayala M, Rodríguez M, González E M and Pérez L. (2007). Fighting cancer with plant-expressed pharmaceuticals. *Trends in Biotechnology* 25(10): 455–459. doi:10.1016/j.tibtech.2007.09.001
- Quiroz-Reyes C N, Aguilar-Méndez M A, Ramírez-Ortíz M E and Ronquillo-De Jesus E. (2013). Comparative study of ultrasound and maceration techniques for the extraction of polyphenols from cocoa beans (*Theobroma cacao* L.). *Revista Mexicana de Ingeniería Química* 12(1): 11–18.
- Ramiro-Puig E and Castell M. (2009). Cocoa: Antioxidant and immunomodulator. *The British Journal of Nutrition* 101(7): 931–40. doi:10.1017/S0007114508169896
- Ramljak D, Romanczyk L J, Metheny-Barlow L J, Thompson N, Knezevic V, Galperin M, Ramesh A and Dickson R B. (2005). Pentameric procyanidin from *Theobroma cacao* selectively inhibits growth of human breast cancer cells. *Molecular Cancer Therapeutics* 4(4): 537–546. doi:10.1158/1535-7163.MCT-04-0286
- Rampersad S N. (2012). Multiple applications of Alamar Blue as an indicator of metabolic function and cellular health in cell viability bioassays. *Sensors* 12(9): 12347–12360. doi:10.3390/s120912347
- Rao G V, Kumar S, Islam M and Mansour S E. (2008). Folk medicines for anticancer therapy: A current status review article. *Cancer Therapy* 6: 913–922.
- Rodgers E H and Grant M H. (1998). The effect of the flavonoids, quercetin, myricetin and epicatechin on the growth and enzyme activities of MCF7 human breast cancer cells. *Chemico-Biological Interactions* 116(3): 213–228. doi:10.1016/S0009-2797(98)00092-1

- Rodríguez-Ramiro I, Ramos S, Bravo L, Goya L and Martín M Á. (2011). Procyanidin B2 and a cocoa polyphenolic extract inhibit acrylamide-induced apoptosis in human Caco-2 cells by preventing oxidative stress and activation of JNK pathway. *The Journal of Nutritional Biochemistry* 22(12): 1186–1194. doi:10.1016/j.jnutbio.2010.10.005
- Ruzaidi A, Amin I, Nawalyah A G, Hamid M and Faizul H A. (2005). The effect of Malaysian cocoa extract on glucose levels and lipid profiles in diabetic rats. *Journal of Ethnopharmacology* 98(1–2): 55–60. doi:10.1016/j.jep.2004.12.018
- Sakano K, Mizutani M, Murata M, Oikawa S, Hiraku Y and Kawanishi S. (2005). Procyanidin B2 has anti- and pro-oxidant effects on metal-mediated DNA damage. *Free Radical Biology & Medicine* 39(8): 1041–1049. doi:10.1016/j.freeradbiomed.2005.05.024
- Salim A A, Chin Y W and Kinghorn A D. (2008). Drug discovery from plants. In K G Ramawat and J M Merillon (eds.). *Bioactive molecules and medicinal plants*. Milan: Springer, 1–5.
- Sarker S D, Latif Z and Gray A I. (2005). Natural product isolation. In S D Sarker, Z Latif and A I Gray (eds.). *Methods in biotechnology*. Totowa, NJ: Humana Press, 1–26.
- Sarker S D and Nahar L. (2012). An introduction to natural products isolation. In S D Sarker and L Nahar (eds.). *Methods in molecular biology: Natural products isolation*. Totowa, NJ: Humana Press, 1–26. doi:10.1007/978-1-61779-624-1
- Sasidharan S, Chen Y, Saravanan D, Sundram K and Latha L. (2010). Extraction, isolation and characterization of bioactive compounds from plants' extracts. *African Journal of Traditional, Complementary and Alternative Medicines* 8(1): 1–10. doi:10.4314/ajtcam.v8i1.60483
- Sathiya M and Muthuchelian K. (2010). Antitumor potential of total alkaloid extract from *Tabebuia rosea* (Bertol.) DC. leaves on MOLT-4 cells in vitro. *Nature and Science* 8(9): 77–85.
- Shafi G, Munshi A, Hasan T N, Alshatwi A A, Jyothy A and Lei D K Y. (2009). Induction of apoptosis in HeLa cells by chloroform fraction of seed extracts of *Nigella sativa*. *Cancer Cell International* 9(29): 1–8. doi:10.1186/1475-2867-9-29
- Shoji T, Masumoto S, Moriichi N, Kobori M, Kanda T, Shinmoto H and Tsushida T. (2005). Procyanidin trimers to pentamers fractionated from apple inhibit melanogenesis in B16 mouse melanoma cells. *Journal of Agricultural and Food Chemistry* 53(15): 6105–6111. doi:10.1021/jf050418m
- Sticher O. (2008). Natural product isolation. *Natural Product Reports* 25(3): 517–554. doi:10.1039/b700306b
- Sun B and Karin M. (2008). NF-kappaB signaling, liver disease and hepatoprotective agents. *Oncogene* 27(48): 6228–6244. doi:10.1038/onc.2008.300
- Supino R. (1995). MTT assays. In S O'Hare and C K Atterwill (eds.). *In vitro toxicity testing protocols*, vol. 43. Totowa, NJ: Humana Press, 137–149.
- Talaviya P. (2011). Anticancer approach with natural product. *International of Pharmaceutical Sciences and Research* 2(10): 2514–2520.
- Tomas-Barberan F A, Cienfuegos-Jovellanos E, Marín A, Muguerza B, Gil-Izquierdo A, Cerda B, Zafrilla P *et al.* (2007). A new process to develop a cocoa powder with higher flavonoid monomer content and enhanced bioavailability in healthy humans. *Journal of Agricultural and Food Chemistry* 55(10): 3926–3935. doi:10.1021/jf070121j
- Wang H, Cheng H, Wang F, Wei D and Wang X. (2010). An improved 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) reduction assay for evaluating the viability of *Escherichia coli* cells. *Journal of Microbiological Methods* 82(3): 330–333. doi:10.1016/j.mimet.2010.06.014

- Wang H, Wang F, Tao X and Cheng H. (2012). Ammonia-containing dimethyl sulfoxide: An improved solvent for the dissolution of formazan crystals in the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) assay. *Analytical Biochemistry* 421(1): 324–326. doi:10.1016/j.ab.2011.10.043
- Wang L and Weller C L. (2006). Recent advances in extraction of nutraceuticals from plants. *Trends in Food Science & Technology* 17(6): 300–312. doi:10.1016/j.tifs.2005.12.004
- Wang P, Henning S M and Heber D. (2010). Limitations of MTT and MTS-based assays for measurement of antiproliferative activity of green tea polyphenols. *PloS One* 5(4): e10202. doi:10.1371/journal.pone.0010202
- Wijngaard H, Hossain M B, Rai D K and Brunton N. (2012). Techniques to extract bioactive compounds from food by-products of plant origin. *Food Research International* 46(2): 505–513. doi:10.1016/j.foodres.2011.09.027
- Wollgast J and Anklam E. (2000). Review on polyphenols in *Theobroma cacao*: Changes in composition during the manufacture of chocolate and methodology for identification and quantification. *Food Research International* 33(6): 423–447. doi:10.1016/S0963-9969(00)00068-5
- Yilmaz Y and Toledo R T. (2006). Oxygen radical absorbance capacities of grape/wine industry byproducts and effect of solvent type on extraction of grape seed polyphenols. *Journal of Food Composition and Analysis* 19(1): 41–48. doi:10.1016/j.jfca.2004.10.009
- Zainal B, Akim A, Taufiq-Yap Y, Hamid R and Kasran R. (2014a). In vitro antioxidant and antiproliferative activities of methanolic plant part extracts of *Theobroma cacao*. *Molecules* 19(11): 18317–18331. doi.org/10.3390/molecules191118317
- Zainal B, Akim A, Taufiq-Yap Y and Kasran R. (2014b). Anticancer agents from non-edible parts of *Theobroma cacao*. *Natural Products Chemistry & Research* 2(4): 1–8. doi.org/10.4172/2329-6836.1000134
- Zhang D, Figueira A, Motilal L, Lachenaud P and Meinhardt L W. (2011). *Theobroma*. In C Kole (ed.). *Wild crop relatives: Genomic and breeding resources*. Berlin: Springer, 277–296. doi:10.1007/978-3-642-21201-7
- Zhang W-Y, Liu H-Q, Xie K-Q, Yin L-L, Li Y, Kwik-Urbe C L and Zhu X-Z. (2006). Procyanidin dimer B2 [epicatechin-(4beta-8)-epicatechin] suppresses the expression of cyclooxygenase-2 in endotoxin-treated monocytic cells. *Biochemical and Biophysical Research Communications* 345(1): 508–515. doi:10.1016/j.bbrc.2006.04.085
- Zhao J, Wang J, Chen Y and Agarwal R. (1999). Anti-tumor-promoting activity of a polyphenolic fraction isolated from grape seeds in the mouse skin two-stage initiation-promotion protocol and identification of procyanidin B5-3'-gallate as the most effective antioxidant constituent. *Carcinogenesis* 20(9): 1737–1745. doi:10.1093/carcin/20.9.1737