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REVIEW

Controversial usages of kratom (*Mitragyna speciosa*): For good or for evil

Murtadha Basheer, Rana Khudhair Jasim, Gam Lay Harn

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Abstract

Kratom (*Mitragyna speciosa*) is a plant that grows well in tropical climates such as in Southeast Asia. Traditionally, people discovered it possessed a stimulating effect that relieved tiredness. Furthermore, it contains analgesic and medicinal properties for the treatment of pain, diarrhea, muscle discomfort, and blood pressure and to enhance stamina. Nevertheless, long term or regular consumption of kratom leads to addiction. This is because the main alkaloid of kratom, mitragynine, binds to opioid receptors and exerts a euphoric effect similar to that of morphine, which may lead to death. Due to this reason, kratom has been listed as a regulated substance in many countries including the United States, Thailand, Malaysia, Bhutan, Finland, Lithuania, Denmark, Poland, Sweden, Australia, and Myanmar. Usages of kratom carry two pharmacological effects depending on dosage. Low-dose kratom exerts a stimulating effect that refreshes the user. High-dose kratom exerts sedative effects that can lead to addiction similar to that of morphine. Despite the euphoric effect of kratom, the beneficial values of kratom to human health is indisputable. Therefore, a complete banning of kratom may cause a loss to pharmaceutical industry. Rather, a controlled or selective usage of kratom will be a better choice.

Key Words: Kratom; Opioid; Pharmacological actions; Toxicity; Addiction; Herbal plant

Core Tip: Traditionally, people discovered kratom (*Mitragyna speciosa*) possessed a stimulating effect that relieved tiredness. Long term or regular consumption of kratom leads to addiction because the main alkaloid of kratom binds to opioid receptors and exerts a euphoric effect. Due to this reason, kratom has been listed as a regulated substance in many countries. Despite the euphoric effect of kratom, the beneficial values of kratom to human health is indisputable. Therefore, a complete banning of kratom may cause a loss to pharmaceutical industry. Rather, a controlled or selective usage of kratom will be a better choice.

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INTRODUCTION

Kratom (*Mitragyna speciosa*) (Figure 1) is a plant native to Southeast Asia. It has been planted as a recreational herb due to its analgesic properties[1]. Kratom was originally recorded for its stimulating effect. The leaves of the tree that are exploited for its pharmacological actions contain different colored veins (white, green, or red) that have been connected to a variety of effects[2]. The red vein leaf is popular in Thailand for its potency[3]. Traditionally, the raw leaves were chewed for their analgesic and soothing effect[2]. In addition, kratom leaves have been used to treat diarrhea, muscle discomfort, decrease blood pressure, and enhance stamina in Southeast Asia[4]. Antispasmodic, muscle relaxant, and antidiarrheal properties of kratom are still in use in the region, while its stimulant and analgesic effects are popular home remedies[3,5].

Folk medicine in Southeast Asia has recognized kratom as an herb[6] in the form of "herbal tea." Its use in the searing heat of the tropics helps workers stay alert and productive. Kratom is widely used to wean morphine addicts off the drug[7]. In fact kratom was utilized historically as an opioid substitute, and it was once widely used in Malaysia and Thailand as an opium replacement and countermeasure [8].

Nevertheless, kratom use has been banned by the local government in Malaysia[8], where it was classified as a poison under the Poison Act[6]. In Thailand, kratom was classified as a Schedule 5 substance under the Thai Narcotics Act. Bhutan, Finland, Lithuania, Denmark, Poland, Sweden, Australia, and Myanmar have kratom under control or regulation[6]. The United States also regulated the use of kratom when the United States Drug Enforcement Administration classified it as a drug of concern[9]. The Centers for Disease Control and Prevention (CDC) released a study on the harmful effects of kratom use on health, where 660 reports on the exposures were documented[10]. In addition, the CDC also documented hundreds of deaths connected with kratom usage[11,12]. Furthermore, the Food and Drug Administration does not acknowledge it as a recognized supplement. Subsequently, the prominence of kratom in the American psyche was reintroduced, where mitragynine and 7-hdroxymitragynine were announced as substances to be added to Schedule I of the Controlled Substances Act by the Drug Enforcement Administration. The Drug Enforcement Administration statement classified the chemicals as Schedule I, meaning kratom has no recognized medicinal value and a significant potential for misuse[13]. Despite all these regulations, several nations continue to allow kratom use today as there is no conclusive evidence that kratom use has the same negative health consequences as conventional opioids[14].

Although the Poisons Act of 1952 makes it illegal to consume kratom in Malaysia, the native tree and tea decoctions are abundantly available in the country[15]. In the United States, kratom products can be purchased from shops and online distributors. Kratom products are available in a variety of forms, including tablets, tea drinks, and powders[10,15]. Increased sales of kratom in Europe and North America have increased worries about its safety and prompted some European governments to prohibit the plant and its active alkaloids[16].

Kratom was legalized in Thailand in 2018 for therapeutic use after a prohibition on its usage, manufacture, and possession was overturned[17]. Following this legalization, many other countries may follow suit. In view of the potential negative effects of kratom, would this legalization be beneficial to society?

PHARMACOLOGICAL ACTIVE ALKALOIDS OF KRATOM

More than 40 compounds were isolated and chemically characterized from *Mitragyna speciosa* since the 1960s[18]. Thus far, only four of these components are pharmacologically active, namely mitragynine, 7-

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Figure 1 Kratom plant.

hydroxymitragynine, speciociliatine, and corynantheidine[19,20]. Mitragynine is the most common alkaloid of the kratom plant[21], and it can be easily oxidized[21]. Mitragynine makes up 66% of the alkaloid content of kratom. On the other hand, 7-hydroxymitragynine was identified as a minor ingredient of kratom leaves extract[6] that makes up 0.04% of the alkaloids[22]. Speciogynine, paynantheine, and mitraphylline are also indole alkaloids of kratom[23]. These compounds are not pharmacologically active, but they contribute synergistically to the overall effect of kratom that formed the diversity of alkaloids found in kratom extracts.

REPORTED MECHANISMS FOR PHARMACOLOGICAL EFFECTS OF KRATOM

Mitragynine and 7-hydroxymitragynine have the ability to target opioid receptors, yet their binding affinity to opioid receptors is significantly different[24]. Mitragynine has a lower binding affinity to opioid receptors than morphine, while 7-hydroxymitragynine is significantly more powerful than either, which is approximately 46 times the potency of mitragynine and 13 times the potency of morphine[25,26]. Therefore, 7-hydroxymitragynine has been targeted as the most important factor in the development of addiction and toxicity, while mitragynine poses a small danger[27,28]. The greater binding affinity of 7-hydroxymitragynine to opioid receptors is due to the addition of a hydroxyl group at the C7 position[19]. Both mitragynine and 7-hydroxymitragynine have been demonstrated to work as agonists, with mitragynine activating primarily μ- and δ-receptors and 7-hydroxymitragynine activating primarily μ- and κ-receptors[26,29,30]. Nonetheless, contradictory evidence suggests a different view. Rather than acting as simple agonists, mitragynine and 7-hydroxymitragynine appear to exert differential effects on distinct receptors[21] in which mitragynine and 7-hydroxymitragynine exert both agonistic and antagonistic characteristic upon binding to opioid receptors. On the other hand, they are partial agonists to μ-receptors, competitive antagonists to δ-receptors, and their effects on κ-receptors are very minimal[31].

Kratom contains indole alkaloids. These indole alkaloids are structurally and pharmacodynamically unlike its opioid rival. Therefore, they were identified as atypical opioids in order to distinguish them from morphine, semisynthetic opioids, and endogenous ligands[32]. Upon binding to opioid receptors, the indole alkaloids (such as kratom alkaloids) activate G-protein-coupled receptors. However, unlike conventional opioids (such as morphine), indole alkaloids do not initiate the β-arrestin pathway when they activate G-protein-coupled receptors[5]. This process refers to biased agonism or ligand-directed signaling that permits a single receptor to exert numerous distinct intracellular effects by selectively disabling the receptor's various signaling cascades[33]. It is worth noting that symptoms of opioid use like respiratory depression, sleepiness, and constipation are due to β-arrestin recruitment[34,35]. The selective β-arrestin inactivation by mitragynine is a desirable trait for an opioid. Therefore, mitragynine may serve as a useful template for the development of novel opioids with more tolerable side effects [21].

Apart from its opioid-like analgesic actions, mitragynine appears to inhibit pain signals *via* other pathways than morphine. Implying a multimodal involvement in pain perception regulation. For example, mitragynine bears a high degree of structural similarity to yohimbine, another indole alkaloid with well-documented adrenergic effects[24]. Due to this similarity, mitragynine analgesic properties

appear to act similarly as yohimbine, which is through activating the α-2 adrenergic postsynaptic receptors[36,37]. α-2 receptors are found in pain modulatory "descending" pathways. These pathways constitute a significant improvement in complicated neurobiological knowledge of pain[38,39]. Another study showed that mitragynine inhibits neuronal pain transmission *via* Ca^{2+} channel blockage[30]. When cellular connections are considered, the release of neurotransmitters was inhibited from the nerve terminals of the vas deferens[2] by the occlusion of neuronal Ca^{2+} channels[6,40].

The indirect analgesic qualities have been ascribed to anti-inflammatory activities of mitragynine, which are thought to be mediated through the suppression of *COX-2* and prostaglandin E2 mRNA expression[41,42]. Apart from these antinociceptive properties, mitragynine exhibits some affinity for D2 dopamine receptors, A2A adenosine receptors, and 5-HT2C and 5-HT7 serotonin receptors. All these belong to central nervous system receptors. Although the physiological significance of these interactions is unknown[30], postsynaptic α-2 adrenergic receptor stimulation and serotonergic 5-HT2A receptor blockage were reported to cause stimulant action of the central nervous system[43,44].

G-protein-biased signaling mechanism of action of mitragynine and 7-hydroxymitragynine makes kratom act as a partial agonist in terms of respiratory depressant effects[31,45,46]. The physiological impact of kratom is a combination of stimulant and sedative, depending on the dose. Stimulant effects are predominant at low dosages, while sedative effects are predominant at higher dosages[15,47]. This differential effect is due to the assortment of alkaloids shown in kratom extricates, which is a distinctive potential pharmacodynamic property of kratom[15,47]. At larger doses, kratom possesses unique narcotic qualities that blend psychostimulant and opiate-like effects[48]. Chronic usage of kratom has been linked to dependency[39].

PHARMACOLOGICAL EFFECTS OF KRATOM LEAVES

Consumption of 5-15 g of kratom leaves is believed to give opioid-like effects[24]. The euphoric effects begin around 10 min after consuming a few grams of dried leaves. At this dosage, kratom may give pain relief and alleviate symptoms of opioid withdrawal, with diarrhea as a possible side effect. Euphoria is more frequently attained at this higher level. Nevertheless, the effects are typically less powerful than with opioid medications[24]. Consumption of more than 15 g of kratom leaves could cause stupor, similar to the effects of opioids[24]. Most people will first suffer sweating, nausea, and dizziness. The early pleasure and tiredness are quickly replaced by a tranquil and dreamy state[44]. Tremors, anorexia, weight loss, convulsions, and psychosis have been reported in regular kratom users[6,24] who consumed high doses of kratom in a short period of time[6,24].

Synergistic effects of mitragynine and 7-hydroxymitragynine produce the analgesic effect desired by kratom users for self-treatment of pain and anxiety. Whilst these alkaloids exert sedative effects at high dosages (5-15 g), they exert stimulating effects at low levels (1-5 g)[44,47]. A dosage of 1-5 g of raw leaves is considered a low to moderate dose[16,24]. This dose is frequently associated with the stimulant effects frequently employed by laborers to combat weariness[24] and achieve greater work capacity while increasing attentiveness, sociability, and libido. Additionally, users may experience normal to slightly constricted pupils and blushing at this dosage. In general, adverse effects are mild. Nonetheless, anxiety and internal agitation have been reported[24]. Other effects of mitragynine included inhibition of ileum motility[7], smooth muscle contraction[49], and stomach acid production[50].

PHARMACOKINETICS AND DRUG-DRUG INTERACTIONS OF KRATOM

Kratom users should anticipate the full effects within 30-60 min after administration; however onset can occur as early as 10-20 min. Mitragynine and 7-hydroxymitragynine have half-lives of approximately 3.5 h and 2.5 h, respectively. Both are mostly removed from the body *via* urine[24,51]. The effects of kratom normally last between 5-7 h, with the biggest effects occurring between 2 and 4 h after administration. However, mild side effects can persist up to a day[24,43,52,53].

Kratom metabolism is primarily hepatic, and there is evidence that it can influence the metabolism and efficacy of other medicines by inducing drug-metabolizing enzymes, namely CYP450s and UDP-glucuronosyl transferase (UGT)[54]. The effects of kratom on human recombinant CYP450 enzyme activity have been studied in various research[55]. Herb-drug interactions were observed when mitragynine was used with herbal or modern medications that share the same metabolic pathway[56]. Mitragynine has a half-life of as little as 3 h, although it may be longer as suggested by others[57,58]. Significant advancement in kratom pharmacology conception revealed that mitragynine is transformed *in vivo via* hepatic metabolism into 7-hydroxymitragynine[59-61]. As a result, it has been hypothesized that 7-hydroxymitragynine is the active metabolite of mitragynine responsible for the majority, if not all, of the effects usually ascribed to the mitragynine precursor. Mitragynine is activated by CYP34A-mediated dehydrogenation, a mechanism akin to how opiates such as codeine are activated *via* CYP2D6-mediated dehydrogenation. In spite of the fact that 7-hydroxymitragynine is found in kratom extracts at minimal levels, the endogenous synthesis of 7-hydroxymitragynine from mitragynine was

significant[59,60,62].

In contrast to oral treatment, intravenous injection of mitragynine in rats was shown to be rapidly distributed to the peripheral compartments through systemic circulation or the central compartment[63, 64]. Mitragynine has a high intestinal permeability in rats. Mitragynine and 7-hydroxymitragynine can pass the blood-brain barrier and are dispersed throughout the brain. Mitragynine has a larger blood-brain barrier permeability and is more readily absorbed into brain tissue than 7-hydroxymitragynine[62, 65]. Mitragynine and 7-hydroxymitragynine inhibit P-glycoprotein[58,61]. These findings indicate that kratom not only penetrates the blood-brain barrier but also inhibits the brain from excreting other compounds *via* the P-glycoprotein efflux mechanism, hence enhancing the bioavailability of sensitive medicines.

Given the rise of reports on toxicity when used in combination with other drugs[66-70], it is worthwhile to investigate the pharmacological interactions of kratom. Drug-drug interactions by modulation of hepatic P450 activity and drug metabolism have been demonstrated in animal investigations[54,55]. Mitragynine appears to inhibit hepatic demethylases, transferases, and the glucuronidation reaction spurred by UGT like UGT2B7 and UGT1A1[71-74]. This has a major indication for the possibility of interaction of kratom and other UGT substrates, such as buprenorphine and ketamine, which are metabolized by UGT2B7[74]. These findings have been cited as a possible explanation for cases of toxicity associated with co-administration of kratom and other drugs, including a fatality associated with supratherapeutic doses of a prescription antipsychotic concomitant with kratom ingestion[67].

A proposed explanation for drug-drug interactions is the effect of kratom on the cytochrome P450 system, a set of enzymes involved in the metabolism of a wide variety of drugs[75]. Two of the most important enzymes involved in drug metabolism are CYP2D6 and CYP3A4. Mitragynine inhibits CYP2C9 and CYP2D6 in a noncompetitive manner and CYP3A4 competitively[56] indicating that kratom has tremendous interaction potential[75]. The largest inhibitory impact is observed for CYP2D6 and CYP3A4, indicating compounds that share the same metabolic route may contribute to unfavorable interactions[55,56]. Due to the inhibitory effects of kratom, substrates for these enzymes may accumulate, leading a typically safe dosage to reach hazardous levels. Thus, while one of kratom's active ingredients, 7-hydroxymitragynine, is mostly responsible for the herb's sedative and analgesic properties, the other active ingredient, mitragynine, may be the cause of unfavorable medication interactions *via* its influence on cytochrome P450 enzymes. It is obvious that identifying herbs as possible medication inhibitors may assist or limit the risk of adverse effects associated with herb–drug interactions[55].

BENEFIT AND RISK OF KRATOM USAGE

Concerns regarding the potential of kratom dependency and addiction in humans are well founded[30, 76,77]. However, for many frequent users, the primary objective was merely to avoid weariness and to boost energy. In such instances, frequent usage may not be defined as dependency or addiction but rather as a desire to increase productivity[78]. This is consistent with "drug instrumentation" hypotheses, according to which a substance is used for a specific, planned aim[6,79]. Long-term use of kratom may result in adaptation, where outright addiction was reported under certain circumstances [76]. It has been suggested that a considerable percentage of kratom usage happens as a substitution for more hazardous drugs, particularly opioids in individuals who already have a history of substance misuse. In these circumstances kratom use is considered harm reduction rather than drug abuse[6,80].

Apart from its misuse potential, kratom poses a slew of additional dangers to patients, mostly as a result of its status as an unregulated supplement. Nothing can be done to assure the veridicality, pureness, grade, and safety of commercially accessible kratom formulations in the absence of governmental control[81]. As a result, it is impossible to determine exactly what is contained in commercially available kratom formulations. Furthermore, the quantity of mitragynine can vary significantly[22]. There have been reports that kratom products can be enhanced in potency by intentionally raising the quantity of 7-hydroxymitragynine[82]. Additionally, many cases of purposeful adulteration of kratom have been observed, including the insertion of synthetic drugs such as phenylethylamine or O-desmethyltramadol, both resulting in patient fatalities[83,84]. Additional dangers include purposeful or accidental product contamination. Laboratory and epidemiological evidence in 2018 specified that kratom was the cause of salmonella infestation[85]. In addition, there have been instances of kratom products being sold that were later shown to have dangerous heavy metal impurities[12].

ADVERSE EFFECTS OF KRATOM USAGE

Kratom side effects, particularly for regular heavy kratom users, were agitation (18.6%), followed by tachycardia (16.9%), sleepiness (13.6%), and disorientation (8.1%)[86]. Seizures occurred in 6.1% of patients, hallucinations in 4.8%, and coma in 2.3%. Other symptoms include weight loss, frequent

urination, insomnia, fatigue, constipation, dry mouth, nausea, and hyperpigmentation of the cheeks[43,44]. Withdrawal symptoms due to the sole usage of kratom are too mild to be detected even for heavy users[44]. Apart from the initial adverse effects of kratom consumption, persistent and high-dose use results in various major side effects such as respiratory depression[66]. Injury to the liver, heart, lungs, kidneys, and neurological system are more significant and life-threatening adverse effects[87].

Concurrent use of kratom and other drugs has been associated with the development of focal and generalized tonic-clonic seizures, possibly as a result of the inhibitory effect of the active components of kratom on cytochrome P450 enzymes and P-glycoprotein[88]. Death was reported in 91 (59.9%) of 152 kratom-positive persons as documented by the unintentional drug overdose reporting system of the United States[89]. Co-administration of kratom and other medicines has the potential to enhance toxicity. A combination of mitragynine and morphine has been found to improve analgesia and delay the development of morphine tolerance in rats[90]. It has been reported that kratom extracts may alleviate symptoms of ethanol withdrawal by lowering alcohol consumption[91].

Muscle relaxation is a common physiological consequence of opiate usage and is frequently noted in kratom users[92]. Mitragynine and other kratom alkaloids may operate similarly to other opiates on the neuromuscular junction[92]. Mitragynine may also cause mild tremors and stiff fingers and toes[93]. This might be explained by the way stimulant and depressive effects are classified at low and high dosages, respectively. Seizures have been observed following kratom usage[92]. Intriguingly, seizures associated with kratom usage doubled in Thailand between 2005 and 2011[16].

A more recent study revealed that kratom caused hepatotoxicity in patients[94]. In addition, kratom-mediated liver damage, stomach pain, jaundice, pruritus, and dark urine were often reported as presenting signs and symptoms[95]. Autopsy results of kratom-related fatalities showed the presence of edema in the brain and lungs, as well as congestion in several organs[96].

A variety of organ systems can be affected due to kratom usage, which include kidney injury[97], cardiotoxicity and arrhythmia[98,99], thyroid injury and hypothyroidism[100], lung injury/acute respiratory distress syndrome[101,102], neonatal abstinence syndrome[103-107], and hepatic injury[108-111]. Amongst these, hepatic injury such as cholestatic hepatitis pattern similar to other drug-related injuries is frequently reported[112]. A number of neurological problems associated with kratom toxicity, including acute brain damage and coma, were documented[112].

Toxicity of kratom is dose-dependent, especially when kratom powder dosages surpass 8 g[86]. An overdose fatality from kratom alone is not common, although it has been reported in the United States and Southeast Asia[113]. This is in line with pharmacologic research and epidemiological investigations of kratom in Southeast Asia. Unlike morphine-like opioids, kratom does not cause life-threatening respiratory depression and is not linked to the personal and societal impairment that morphine-like opioids are linked to[3,8,113].

CONCLUSION

Kratom exerts its pharmacological effects in a dose-dependent manner, where it acts as a stimulant at low doses and a depressant at high doses. Regular usage of kratom can lead to dependency. The cellular mechanisms of kratom are complex and not well understood. The major alkaloid of the kratom leaves, mitragynine, and its minor alkaloid, 7-hydroxymitragynine, are likely responsible for the pharmacological effects of kratom. As the data have shown so far, deaths due to the sole use of kratom are rare. Typically, the combination use of kratom with other illicit drugs are the main causes of death. Given the valuable therapeutic properties of kratom, total banning of kratom will be a great loss to the pharmaceutical industry. Instead controlled usage should be practiced especially in the event of kratom misuse for recreational purposes. Considering both benefits and risks of kratom usage, one can wisely choose to use it for good.

FOOTNOTES

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ORIGINAL ARTICLE

Basic Study

Antidepressant-like potential of silymarin and silymarin-sertraline combination in mice: Highlighting effects on behaviour, oxidative stress, and neuroinflammation

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Abstract

BACKGROUND

Currently, there is increasing advocacy for the use of diet, dietary supplements, and herbal remedies in depression management.

AIM

To determine the antidepressant effects of standardized silymarin (SILY) extract either as a sole agent or as an adjunct in depression therapy.

METHODS

Adult mice were assigned into three main groups based on the neurobehavioural models; and each main group had ten treatment groups of 10 mice each. Treatment groups were: Vehicle control group, oral sertraline (SERT) group, two groups fed SILY)-supplemented diet (SILY at 140 and 280 mg/kg of feed, respectively), dexamethasone (DEX; *i.p.*) group, DEX/SERT group, two groups of DEX/SILY (SILY at 140 and 280 mg/kg of feed, respectively), and another two groups of (SERT/DEX/SILY) (SILY at 140 and 280 mg/kg of feed, respectively, plus *i.p.* DEX plus SERT). Duration of the study was 7 wk, and treatments were administered daily.

RESULTS

SILY (alone) increased body weight, open field locomotor activity, rearing, and grooming; it also enhanced spatial working memory while decreasing anxiety-related behaviours and behavioural despair. SILY also improved antioxidant status while decreasing lipid peroxidation, acetylcholinesterase activity, and

inflammatory markers. Neuronal integrity of the cerebral cortex and hippocampus was preserved. Overall, when administered alone or with SERT, SILY counteracted DEX-induced behavioural and biochemical changes while preserving neuromorphological integrity.

CONCLUSION

In conclusion, SILY is beneficial in mitigating DEX-induced central nervous system and other related changes in mice.

Key Words: Behavioural despair; Depression; Mental Health; Neurobehaviour; Neuromorphology

Core Tip: Depression is a neuropsychiatric disorder that has in recent times become a leading cause of disability and a major contributor to global disease burden and suicide. In recent times there has been increasing advocacy for the use of dietary supplements and herbal remedies in depression management. While antidepressant effects of extracts of silybum marianum seeds have been reported, there is a dearth of scientific information on the possible effect of its standardized silymarin extract either as a sole agent or as an adjunct in depression therapy.

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INTRODUCTION

Depression is a neuropsychiatric disorder that has in recent times become a leading cause of disability and a major contributor to global disease burden and suicide[1]. It is characterised by the presence of anhedonia and/or evidence of alterations in mood including irritability, sadness, or emptiness[2-6]. In the last decade or more, the global prevalence of depression has continued to rise[1,7], with depression accounting for approximately 12% of hospital admissions, 50% of mental health consultations, and 4% of suicides[6,8,9]. In addition to a high socioeconomic burden and significant morbidity/mortality, depression has been ranked as the single largest contributor to global disability and suicide deaths[3,5,10-13]. Scientific evidence[14,15] of the critical role of serotonin in the pathogenesis of depression was instrumental to the development of some of the current antidepressant drugs (fluoxetine and sertraline [SERT]) that selectively inhibit the reuptake of serotonin at serotonin transporters, and thereby increase serotonin concentration within the synaptic cleft[15,16]. While significant strides have been made in developing newer drugs for the management of depression, the obvious advantages of more tolerable, less toxic, and more affordable treatment options continue to spur researchers to do more.

In recent times, the impact of diet, dietary supplements, and herbal remedies in the maintenance of mental health, as well as the aetiology, progression, and management of mental illness is becoming important areas of research[17-19]. Specifically, the search for modifiable factors in depression has led to the study of the possible associations between the development of depressive illness and dietary patterns. A number of studies have been successful in demonstrating the value of diet and/or dietary supplements including selenium, zinc, and vitamins B, C, and K in the prevention, pathogenesis, or outcome of depression[20-25]. The antidepressant effects of extracts of parts of plants such as the *Silybum marianum* seed have also been reported[26].

Silymarin (SILY) is a polyphenolic antioxidant complex which is derived from the fruit and seeds of the 'milk-thistle' plant known as *Silybum marianum*. While this ancient medicinal plant has been used for centuries for hepatoprotection (or the management of hepatic disorders), the production of standardised fractions of the plant has allowed for a widespread research of its medicinal potential[27-29]. The antifibrotic, antioxidative, immunomodulatory, anti-inflammatory, and antinociceptive properties of SILY have been documented[30-33], and at pharmacological doses, it has been reported to be non-toxic[30,34]. A number of studies have also reported the neuroprotective effects of SILY in different animal models[26-28,35-37]. While there have been suggestions of the possible antidepressant effects of *Silybum marianum* extracts, there is a dearth of scientific information on the possible antidepressant effects of standardised formulations of SILY used alone or as an adjunct. Therefore, this study evaluated the effects of dietary supplementation with SILY, alone or in combination with SERT, on body weight, food intake, neurobehaviour, oxidative stress parameters, inflammatory markers, and acetylcholinesterase

levels in a dexamethasone (DEX) model of depression in mice.

MATERIALS AND METHODS

Drugs and chemicals

SILY (Silybon-70® Micronova Pharmaceutical Industries Ltd, Lagos Nigeria), SERT capsules (Zoloft® 50 mg, Pfizer Inc. Lagos, Nigeria), and DEX phosphate injection (4 mg/mL, Vixa Pharmaceutical Co. Ltd, Lagos, Nigeria) were obtained commercially. Assay kits for lipid peroxidation (malondialdehyde [MDA] assay kit), glutathione peroxidase (GPx), reduced glutathione (GSH), superoxide dismutase (SOD), and catalase (Biovision Inc. Milpitas, CA, United States) were obtained and refrigerated until used. All other chemicals were of analytical grade.

Animals

Adult male Swiss mice (Empire Breeders, Osogbo, Osun State, Nigeria) weighing between 18-25 g each were used for this study. Mice were housed singly in cages located in temperature-controlled quarters (22 °C-25 °C) with lights on at 7.00 a.m. daily. Animal diet was commercially sourced (TOP® feeds) standard rodent chow (29% protein, 13% fat, and 58% carbohydrate). Mice had access to food and water *ad libitum*, except during the behavioural tests. All procedures were conducted in accordance with the approved protocols of the Ladoke Akintola University of Technology and within the provisions for animal care and use prescribed in the scientific procedures on living animals European Council Directive (EU2010/63).

Feed

Animals were fed commercially available rodent diet [(standard diet (SD)] sourced from Top Feeds Ltd, Ibadan Nigeria). SILY was incorporated into standard rodent diet at 140 and 280 mg/kg of feed, respectively.

Experimental method

Adult male mice were randomly assigned into three main groups (1-3) based on the neurobehavioural models. Group 1 animals were exposed to the elevated plus maze and tail-suspension paradigm, group 2 were exposed to the Y-maze and forced-swim paradigm, while mice in group 3 were exposed to the open-field arena and radial arm maze. Animals in the main groups were subsequently assigned into ten treatment groups of 10 mice each. Treatment groups were: Vehicle control group [fed standard diet (SD) and given intraperitoneal (*i.p.*) saline plus oral saline], SERT group (fed SD and given *i.p.* saline plus oral SERT), two groups fed SILY-supplemented diet (at 140 and 280 mg/kg of feed, respectively; SILY 140 and SILY 280) and given *i.p.* saline plus oral saline, DEX group (fed SD and given *i.p.* DEX plus oral saline), DEX/SERT group (fed SD and given *i.p.* DEX plus oral SERT), two groups (DEX/SILY) fed SILY-supplemented diet (at 140 and 280 mg/kg of feed, respectively) and given *i.p.* DEX plus oral saline (DEX/SILY 140 and DEX/SILY 280), and another two groups fed SILY-supplemented diet (at 140 and 280 mg/kg of feed, respectively) and given *i.p.* DEX plus oral SERT (SERT/DEX/SILY 140 and SERT/DEX/SILY 2800). SERT was administered at 5 mg/kg[38], while DEX was administered at 4 mg/kg[39-41]. Total duration of the study was 7 wk, and all treatments were administered daily. Mice in all groups were weighed weekly (7.00 am, before feeding) and food intake was measured as previously described[42-44] using a weighing balance (Mettler Toledo Type BD6000, Greifensee, Switzerland). Food changes occurred daily at 8.00 am. Food hoppers that contained pre-weighed quantities of food were provided daily to the mice; a thin plastic sheet was placed beneath the cages to catch food spillage. Total food consumption was then measured as the difference between the pre-weighed standard chow and the weight of chow in hopper daily. Crumbs in the plastic sheets were weighed and accounted for in the measurement of total food consumed during the 24-h period[42]. At the end of the experimental period, animals were exposed to the respective paradigms. Twenty-four hours after the last behavioural test, animals in the open field and radial arm maze group were euthanised by cervical dislocation. Blood was taken for assessment of oxidative stress parameters and inflammatory markers (tumor necrosis factor (TNF)–α and interleukin-10). The hippocampus and cerebral cortex were excised and either homogenised for the assessment of inflammatory markers, antioxidant status, and acetylcholinesterase activity or processed for general histological examination.

Assessment of body weight and food intake

Body weight of animals in all groups were measured weekly using an electronic weighing balance (Mettler Toledo Type BD6000, Switzerland) while the amount of food consumed was measured daily. Relative change in body weight or food intake was calculated for each animal using the equation below following which results for all animals where computed to find the statistical mean.

Behavioural tests

Mice were transported in their home cages to the behavioural testing laboratory and allowed to acclimatise (10 min) before exposure to paradigms. Each animal was placed in the apparatus following which behaviours were recorded. On completion of the tests, each mouse was removed from the maze and returned to the respective home cages. The interior surfaces of the mazes were then cleaned with 70% ethanol and wiped dry to remove traces of conspecific odour. Behavioural parameters were then scored manually by independent observers who were blind to the groupings.

Anxiety model: Elevated plus maze

The elevated plus-maze (EPM) is a plus-shaped apparatus with four arms placed at right angles to each other. The EPM used in the study and the procedure are as previously described[42,45,46].

Open field

Ten minutes of locomotion, rearing, and grooming were observed in the open field and scored as previously described[47,48].

Tail suspension test

The tail suspension test (a measure of behavioural despair) was carried out according to the method described by Steru *et al*[49], Młyniec and Nowak[50], and Onaolapo *et al*[51]. Mice were securely fastened (using a medical adhesive tape) by the tip of their tail to a flat platform and suspended for 6 min approximately 30 cm below the platform. The total time of immobility was measured during the 6-min period of the testing session. Immobility, which was defined as the period the animal hung passively without limb movement, was scored[40].

Forced swim test

The forced swim test is a measure of behavioural despair in mice. The test was carried out according to the method described by Porsolt *et al*[52], Kroczka *et al*[53], and Onaolapo *et al*[51]. Mice were dropped individually into glass cylinders which had a height of 25 cm and diameter of 10 cm, were filled with 10 cm of water (water level was marked to ensure uniformity), and maintained at a temperature of 23-25 °C. The dimensions of the glass cylinder ensured that the mouse was unable to touch the bottom of the cylinders either with their feet or their tails, during the test. The height also prevented mice from escaping from the cylinder. Animals were then returned (they were dried with paper towels to prevent hypothermia) to their home cages after 15 min in water. They were reintroduced into the cylinders 24 h later. Mice were exposed to the forced swim paradigm for 6 min. The total duration of immobility was measured during the last 4 min of the forced swim test. The mouse was considered immobile when it had remained floating passively in the water.

Memory tests

The Y- and radial arm mazes were used to assess and score spatial working memory as previously described[54,55]. The Y-maze has three arms (41 cm long and 15 cm high, 5 cm wide at an angle of 120°), while the radial arm maze apparatus has 8 arms measuring 33 cm long spaced equidistantly from each other.

Blood collection

Blood collected from each mouse *via* cardiac puncture was used for the estimation of lipid peroxidation, GSH, SOD, and GPx. Samples were collected into unheparinised bottles and processed as previously described[56,57].

Brain homogenization

Within 24 h of the completion of the behavioural tests, animals in all groups were euthanised by cervical dislocation post-anaesthesia with diethyl ether. Homogenates of the hippocampus and cerebral cortex were prepared in ice-cold phosphate buffered saline, using a Teflon-glass homogeniser. The homogenate was centrifuged at 5000 rpm at 4 °C for 15 mi. The supernatant obtained was then used for estimation of lipid peroxidation levels and antioxidant status.

Biochemical assays

Estimation of MDA content (lipid peroxidation): Lipid peroxidation level was measured as MDA content as previously described[58]. Change in colour was measured at 532 nm. The MDA kit used had a detection range of 7.813-500 ng/mL and a sensitivity < 4.688 ng/mL. The intra-assay coefficient of variability was < 7%, and the inter-assay coefficient of variability was < 9%.

Antioxidant activity

SOD activity was determined using a commercially available assay kit. Colour changes were measured at an absorbance of 560 nm as described previously[29,58]. The activity of SOD is expressed in

units/mL.

Levels of GSH were determined following the instructions of the manufacturer. A yellow-coloured complex which can be measured at an absorbance of 412 nm is formed by GSH form when it reacts with Ellmans reagent (DTNB). Levels of GSH are expressed in nmol/mL.

GPx is an enzyme that catalyses the reduction of hydroperoxides, such as hydrogen peroxide. GPx activity was determined as previously described[29]. The activity of GPx is expressed in units/mL.

Tumour necrosis factor-α and interleukin-10

Tumour necrosis factor-α and interleukin (IL)-10 were measured using enzyme-linked immunosorbent assay (ELISA) techniques with commercially available kits (Enzo Life Sciences Inc. NY, United States) designed to measure the 'total' (bound and unbound) amount of the respective cytokines.

Acetylcholinesterase activity

Brain acetylcholinesterase activity (Biovision, United States) was determined using commercially available assay kits following the instructions of the manufacturer.

Tissue histology

Sections of the cerebral cortex and hippocampus were fixed in 10% formal saline for 24 h, processed for paraffin wax embedding, dehydration, clearing, and infiltration, sectioned, and then mounted following which they were processed for general histological staining using haematoxylin and eosin as previously described[40].

Statistical analysis

Data were analysed using Chris Rorden's analysis of variance (ANOVA) for windows, version 0.98. Data analyses were done by ANOVA, and post-hoc test (Tukey HSD) was used for within and between group comparisons. Results are expressed as the mean ± SEM. $P < 0.05$ was taken as the accepted level of significant difference from control or standards.

RESULTS

Effect of silymarin on body weight

Figure 1 shows the effect of SILY on the change in body weight. There was a significant [F (9, 90) = 48.1, $P < 0.001$] decrease in body weight in the groups administered with SERT, DEX, DEX/SERT, and DEX/SILY 140, while an increase in body weight was observed in groups administered with SILY 140 and SILY 280, DEX/SILY 280, and those administered with *i.p*. DEX, oral SERT, DEX/SERT/SILY 140, and DEX/SERT/SILY 280 compared to the vehicle control. Compared to SERT alone, there was a significant increase in body weight with SILY 280. While compared to DEX, body weight increased significantly with DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, body weight increased significantly with DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone increased body weight compared to the vehicle control or SERT. SILY when administered alone (at 280 mg/kg) reversed DEX-induced changes in body weight. When co-administered with SERT, SILY at both concentrations reversed the changes in body weight induced by DEX.

Effect of silymarin on food intake

Figure 2 shows the effect of SILY on the change in food intake. There was a significant [F (9, 90) = 513, $P < 0.001$] decrease in food intake with DEX, DEX/SERT, DEX/SILY 140, and DEX/SILY 280, while an increase in food intake was observed with DEX/SERT/SILY 140 and DEX/SERT/SILY 280, compared to the vehicle control. Compared to SERT alone, there was no significant difference in food intake in any of the SILY alone groups. While compared to DEX, food intake increased significantly with DEX/SERT/SILY 140 and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, food intake increased significantly with DEX/SERT/SILY 140 and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone did not significantly alter food intake compared to the vehicle control, SERT, or DEX, although co-administration of SILY with SERT was associated with an increase in food intake compared to the vehicle control, DEX, or DEX with SERT.

Effect of silymarin on locomotor and rearing activity

Figure 3 shows the effect of SILY on locomotor activity (upper panel) and rearing (lower panel). There was a significant [F (9, 90) = 26.5, $P < 0.001$] increase in locomotor activity with SILY 140, DEX/SILY 140, and DEX/SILY 280, and a decrease in locomotor activity with DEX compared to the vehicle control. Compared to SERT alone, there was a significant increase in locomotor activity with SILY 140. While compared to DEX, locomotor activity increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group

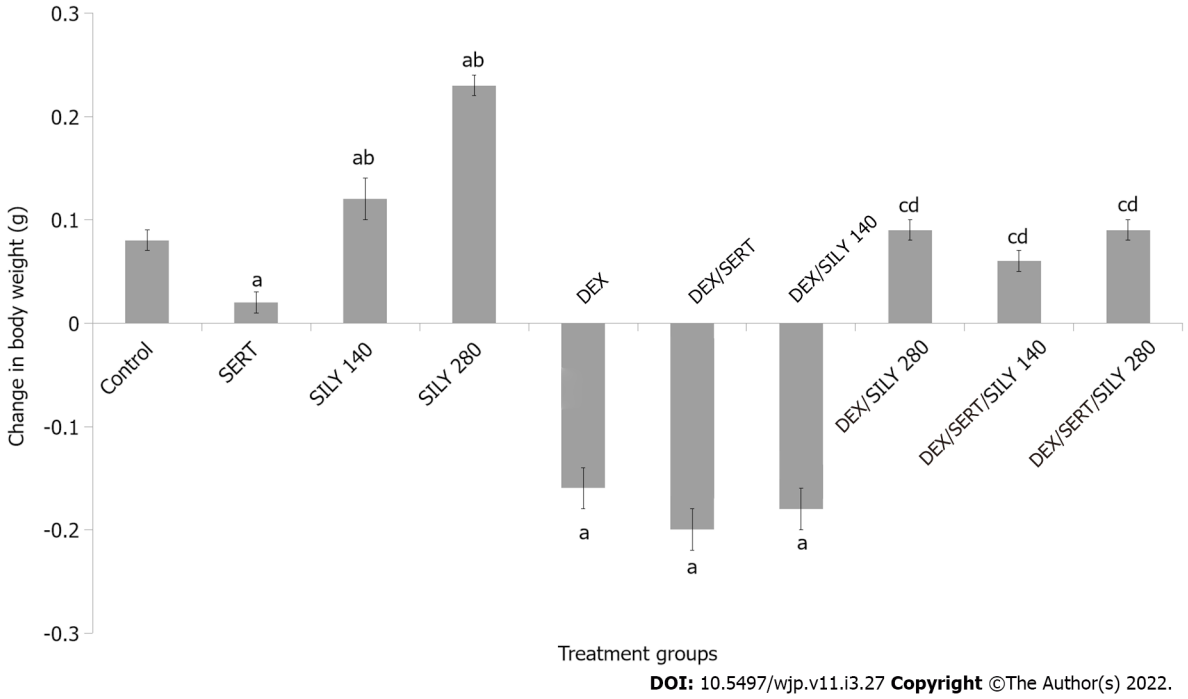

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Figure 1 Effect of silymarin on change in body weight. Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 vs SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

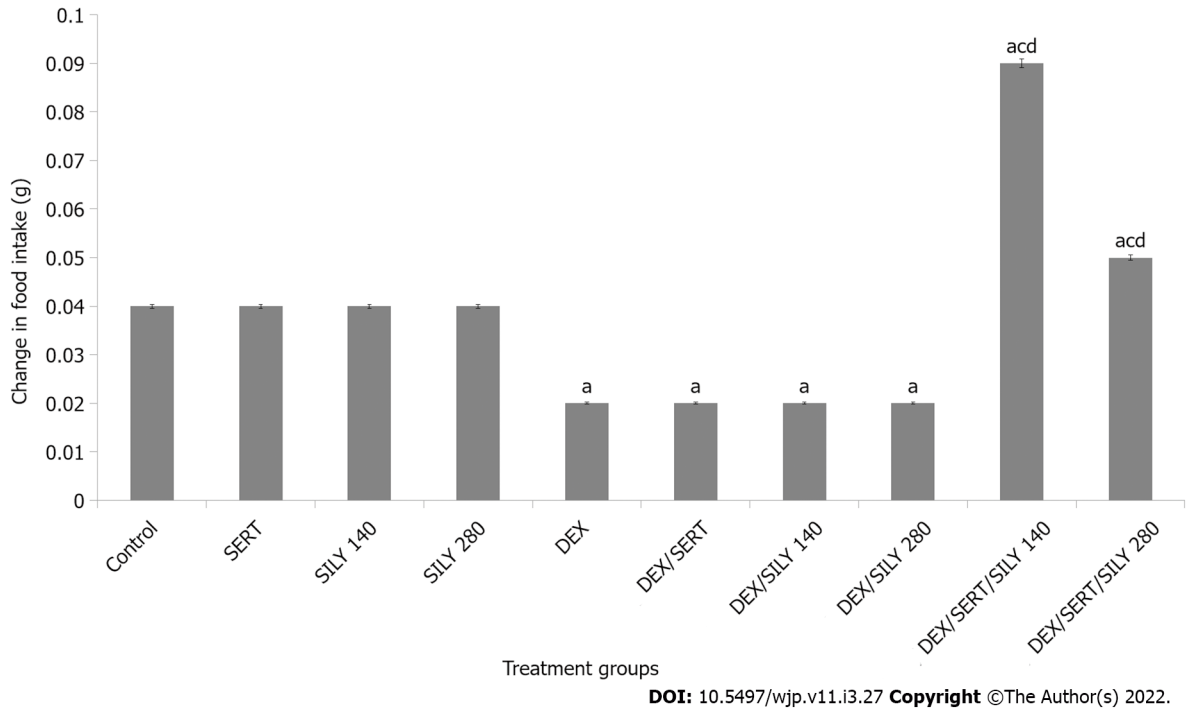

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Figure 2 Effect of silymarin on changes in food intake. Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 *vs* SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

administered with DEX/SERT, locomotor activity increased significantly with DEX/SILY 280 mg. Overall, the results showed that SILY (administered alone) concentration-dependently increased locomotor activity compared to the vehicle control and SERT. SILY alone or co-administered with SERT also mitigated the decrease in locomotor activity induced by DEX.

Rearing activity decreased significantly [F (9, 90) = 6.20, P < 0.001] with DEX and increased with DEX/SILY 140 and DEX/SILY 280, compared to the vehicle control. Compared to SERT alone, there was a significant increase in rearing activity with SILY 140. While compared to DEX, rearing activity

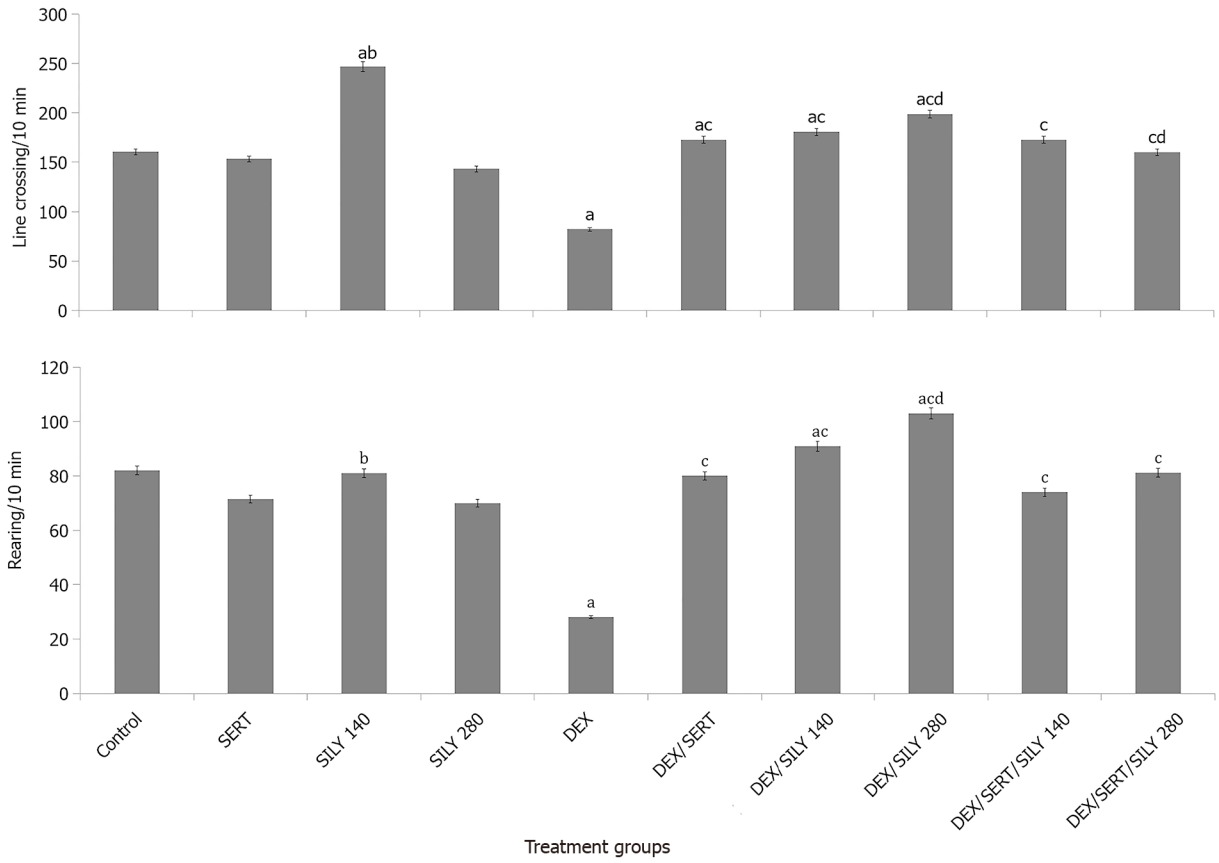

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Figure 3 Effect of silymarin on locomotor activity (upper panel) and rearing activity (lower panel). Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 *vs* SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared to DEX/SERT, the rearing activity increased significantly with DEX/SILY 280. Overall, the results showed that SILY alone or co-administered with SERT also mitigated the decrease in rearing activity induced by DEX.

Effect of silymarin on grooming behaviour

Figure 4 shows the effect of SILY on self-grooming behaviour. There was a significant [F (9, 90) = 5.24, P < 0.001] increase in self-grooming with SILY, DEX/SILY, and DEX/SERT/SILY 140, while a decrease in self-grooming was observed with DEX and DEX/SERT compared to the vehicle control. Compared to SERT alone, there was a significant increase in self-grooming with SILY 140. While compared to DEX, self-grooming behaviour increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, self-grooming increased significantly with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone concentration-dependently increased self-grooming behaviour compared to the vehicle control and SERT. SILY alone or co-administered with SERT also mitigated the decrease in self-grooming behaviour induced by DEX.

Effect of silymarin on spatial working memory in the Y- and radial arm mazes

Figure 5 shows the effect of SILY on radial arm (upper panel) and Y- (lower panel) maze spatial working memory tasks. There was a significant [F (9, 90) = 9.20, P < 0.001] increase in working memory with SILY 140, SILY 280, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, while a decrease in memory was observed with DEX compared to the vehicle control. Compared to SERT alone, there was a significant increase in working memory with SILY 140 and SILY 280. While compared to DEX, working memory increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, working memory increased significantly with DEX/SILY 140, DEX/SILY 280, DEX/ SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone increased spatial working memory scores in the radial arm maze, compared to the

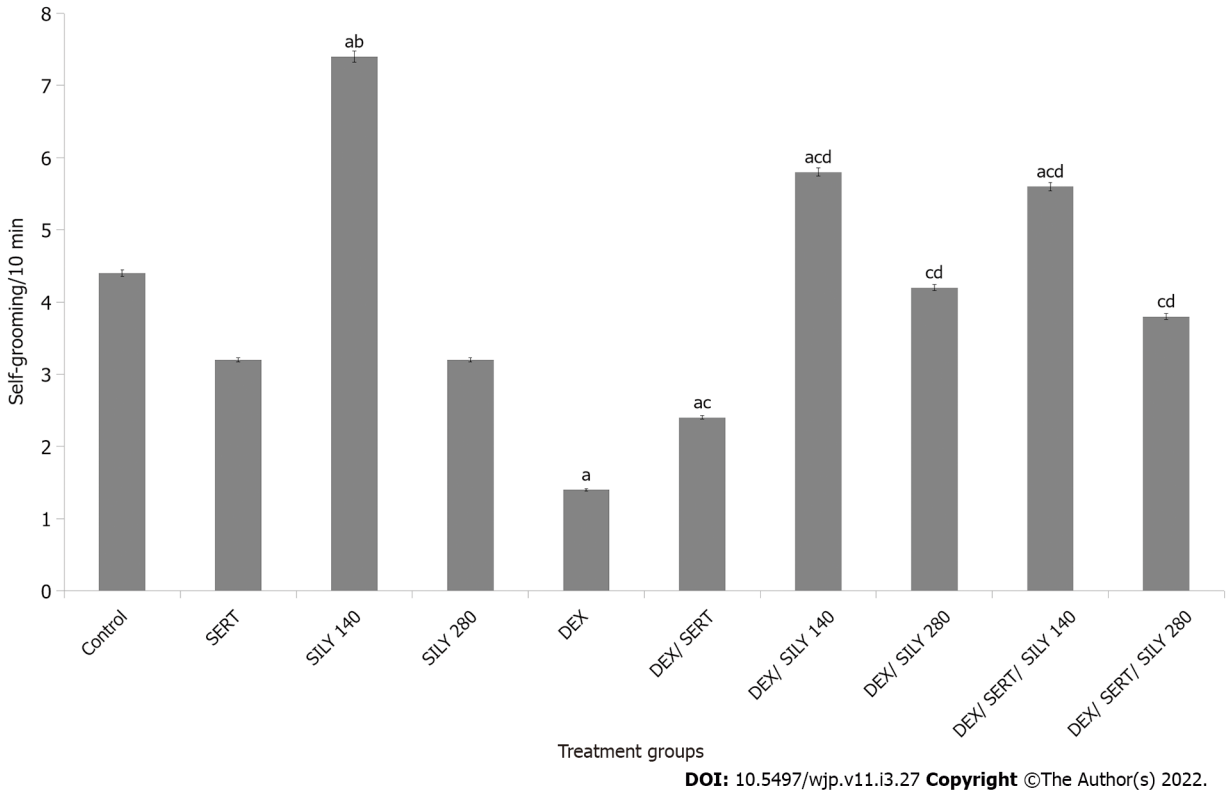

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Figure 4 Effect of silymarin on self-grooming. Each bar represents the mean ± SEM, $^{c}P < 0.05$ *vs* control, $^{b}P < 0.05$ *vs* SERT, $^{c}P < 0.05$ *vs* DEX, $^{d}P < 0.05$ *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

vehicle control and SERT. SILY alone or co-administered with SERT also counteracted the decrease in spatial working memory score induced by DEX.

Y maze spatial working memory increased significantly [F (9, 90) = 16.04, $P < 0.001$] with SILY 140, SILY 280, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and decreased with DEX compared to the vehicle control. Compared to SERT alone, there was no significant difference in working memory in any of the groups fed SILY alone. While compared to DEX, working memory increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared to DEX/SERT, working memory increased significantly with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone improved spatial working memory scores in the Y-maze compared to the vehicle control. SILY alone or co-administered with SERT also counteracted the decrease in spatial working memory induced by DEX.

Effect of silymarin on anxiety-related behaviours

Figure 6 shows the effect of SILY on the time spent in the open (upper panel) and closed (lower panel) arms of the elevated plus maze. There was a significant [F (9, 90) = 15.11, $P < 0.001$] increase in open arm time with SERT, SILY 140, SILY 280, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, while a decrease was observed with DEX compared to the vehicle control. Compared to SERT alone, there was a significant increase in open arm time with SILY 280. While compared to DEX, open arm time increased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, open arm time increased significantly with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone increased the time spent in the open arm of the EPM compared to the vehicle control. SILY alone or co-administered with SERT also mitigated the decrease in open arm time induced by DEX.

Time spent in the closed decreased significantly [F (9, 90) = 8.21, $P < 0.001$] with SERT, SILY 140, SILY 280, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and increased with DEX compared to the vehicle control. Compared to SERT alone, there was no significant difference in closed arm time in any of the groups fed SILY alone. While compared to DEX, closed arm time decreased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with DEX/SERT, the time spent in the closed arm decreased significantly with DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone decreased time spent in the closed arm compared to the vehicle control. SILY alone or co-administered

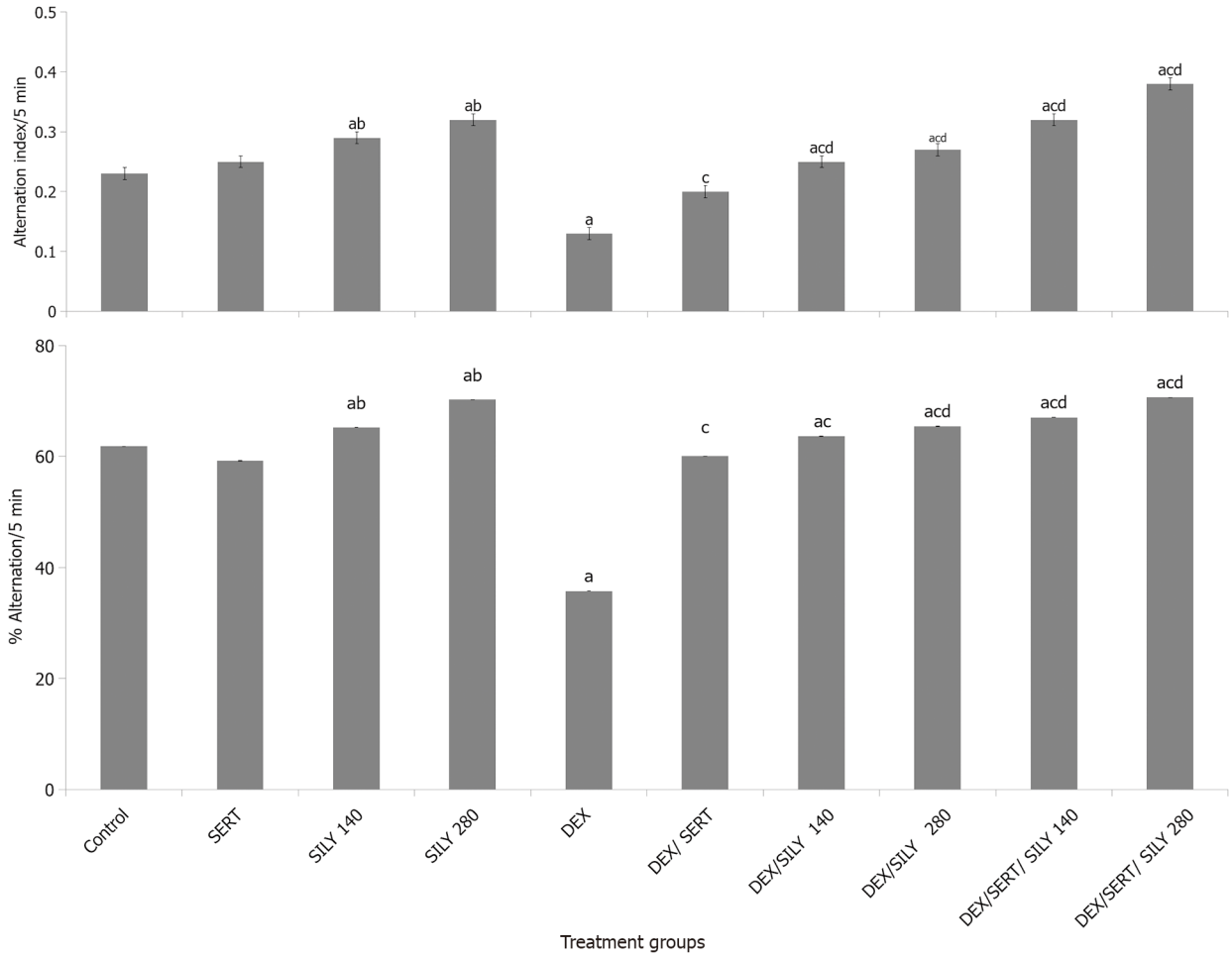

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Figure 5 Effect of silymarin on radial arm maze (upper panel) and Y–maze (lower panel) spatial working memory. Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 *vs* SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

with SERT also decreased time spent in the closed arm compared to DEX.

Effect of silymarin on behavioural despair

Figure 7 shows the effect of SILY on immobility time in the tail suspension (upper panel) and forced swim (lower panel) tests. There was a significant [F (9, 90) = 26.9, P < 0.001] decrease in immobility time with SILY 140, SILY 280, DEX/SERT, and DEX/SERT/SILY 140, and DEX/SERT/SILY 280 while an increase was observed with SERT, DEX, DEX/SILY 140, and DEX/SILY 280 compared to the vehicle control. Compared to SERT alone, there was a significant decrease in immobility time with SILY 140 and SILY 280. While compared to DEX, the immobility time decreased significantly with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, the immobility time decreased significantly with EX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone decreased immobility time compared to the vehicle control and SERT. SILY alone or co-administered with SERT also mitigated the increase in immobility time induced by DEX.

Immobility time in the forced swim test decreased significantly [F (9, 90) = 24.0, p < 0.001] with SERT, SILY 140, SILY 280, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and increased with DEX, compared to the vehicle control. Compared to SERT alone, there was a significant decrease in immobility time with SILY 140. While compared to DEX, the immobility time decreased significantly with DEX/SERT, DEX/SILY 140, and DEX/SERT/SILY. Compared to DEX/SERT, the immobility time decreased significantly with DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone decreased immobility time compared to the vehicle control and SERT. SILY alone or co-administered with SERT also mitigated the increase in immobility time induced by DEX.

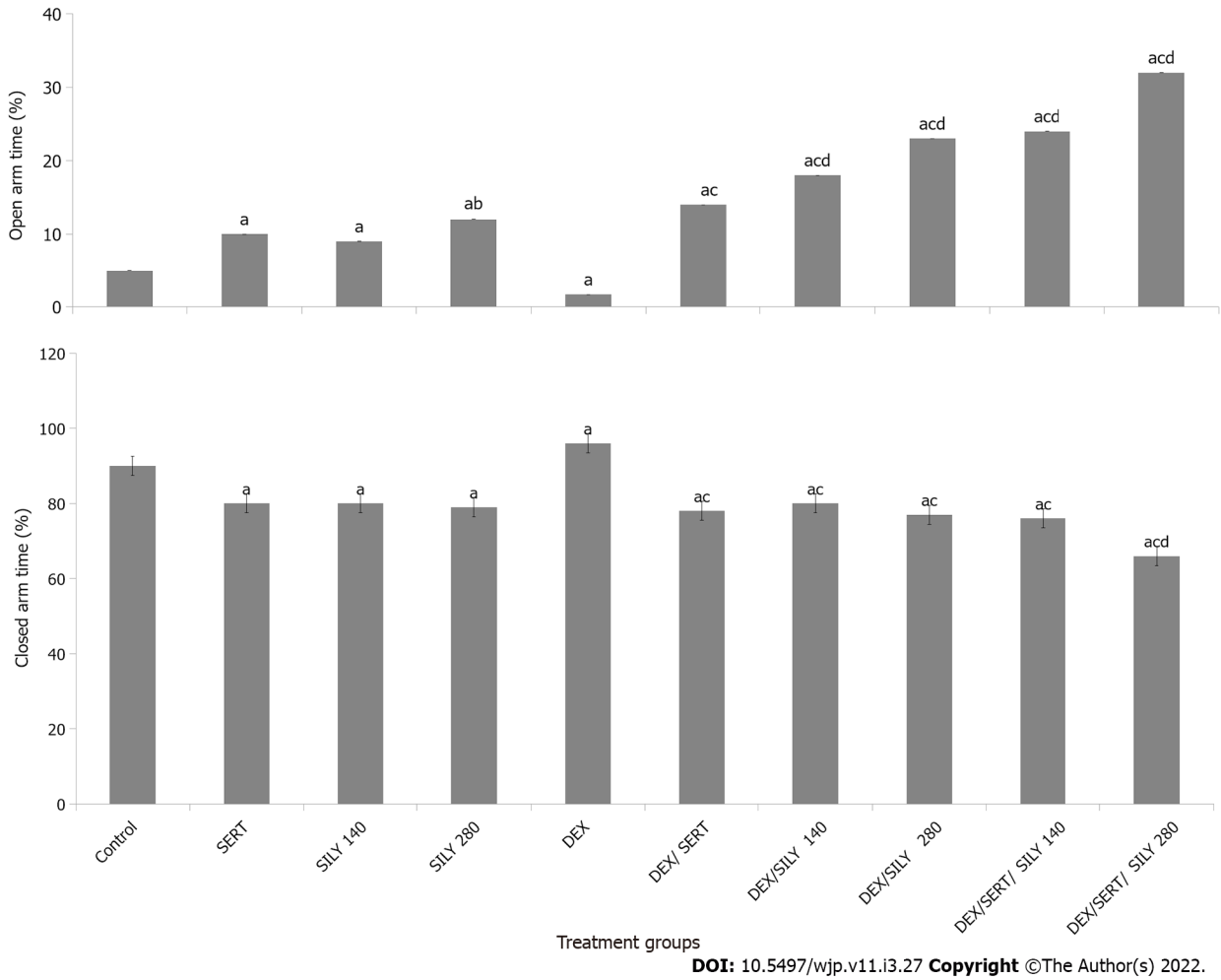

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Figure 6 Effect of silymarin on time spent in the open-arm (upper panel) and closed arm (lower panel) of the elevated plus maze. Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 *vs* SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

Effect of silymarin on serum lipid peroxidation and antioxidant status

Table 1 shows the effect of SILY on serum lipid peroxidation and antioxidant status. SOD [F (9, 90) = 13.11, P < 0.001], increased significantly with SILY 140, SILY 280, and DEX/SILY 280, while a decrease was observed with DEX, DEX/SERT, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and decrease with DEX/SERT. Compared to DEX/SERT, there was an increase in SOD activity with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Catalase [F (9, 90) = 25.32, P < 0.001] increased significantly with SILY 140, SILY 280, and DEX/SILY 280, while a decrease was observed with DEX, DEX/SERT, and DEX/SERT/SILY 140 compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared to DEX/SERT, there was an increase in catalase activity with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280.

GSH [F (9, 90) = 9.23, P < 0.001] increased significantly with SILY 140 and SILY 280, DEX/SILY 280, and DEX/SERT/SILY 280, while a decrease was observed with DEX and DEX/SERT 140 compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared to DEX/SERT, there was an increase in GSH levels with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280.

GPx activity [F (9, 90) = 10.32, P < 0.001] increased significantly with SILY 140 and SILY 280 and decreased with DEX and DEX/SERT compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared to DEX/SERT, there was an increase in GPx levels with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY

Table 1 Serum antioxidant status and lipid peroxidation level

Group	SOD (U/mL)	CAT (U/mL)	GSH nmol/mL	GPx IU/L	MDA μmol/L
Control	0.92 ± 0.02	23.12 ± 0.21	0.73 ± 0.10	11.68 ± 1.10	6.42 ± 0.02
SERT	0.93 ± 0.02	21.11 ± 0.20	0.70 ± 0.11	10.60 ± 2.01	5.40 ± 0.02
SILY 140	1.54 ± 0.11[a,b]	28.72 ± 0.23[a,b]	0.82 ± 0.05[a,b]	24.54 ± 0.34[a,b]	3.38 ± 0.04[a]
SILY 280	1.98 ± 0.02[a,b]	31.76 ± 0.22[a,b]	1.12 ± 0.05[a,b]	30.20 ± 0.78[a,b]	2.33 ± 0.03[a,b]
DEX	0.78 ± 0.03[a]	12.78 ± 0.22[a]	0.30 ± 0.05[a]	6.65 ± 1.10[a]	14.40 ± 0.06[a]
DEX/SERT	0.67 ± 0.01[a,c]	13.67 ± 0.20[a]	0.35 ± 0.01[a,c]	6.92 ± 1.00[c]	14.57 ± 0.16[a]
DEX/SILY 140	0.98 ± 0.01[c,d]	22.16 ± 0.10[c,d]	0.56 ± 0.04[a,c]	11.40 ± 1.23[c,d]	9.65 ± 0.05[a,c,d]
DEX/SILY 280	1.00 ± 0.12[a,c,d]	27.20 ± 0.22[a,c,d]	0.78 ± 0.03[a,c,d]	12.45 ± 1.30[c,d]	5.57 ± 0.01[a,c,d]
DEX/SERT/SILY 140	0.82 ± 0.02[a,c,d]	19.70 ± 0.10[a,c,d]	0.75 ± 0.01[c,d]	10.12 ± 1.01[c,d]	4.98 ± 0.05[a,c,d]
DEX/SERT/SILY 280	0.98 ± 0.02[a,c,d]	21.21 ± 0.20[c,d]	0.88 ± 0.03[a,c,d]	11.32 ± 0.76[c,d]	4.82 ± 0.02[a,c,d]

Values are expressed as the mean ± SEM.
[a]$P < 0.05$ *vs* control.
[b]$P < 0.05$ *vs* SERT.
[c]$P < 0.05$ *vs* DEX.
[d]$P < 0.05$ *vs* DEX/SERT. SOD: Superoxide dismutase; GPx: Glutathione peroxidase; MDA: Malondialdehyde; SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment.

140, and DEX/SERT/SILY 280.

Overall, the results showed that SILY administered alone or co-administered with SERT had a mixed response with regards to antioxidant status.

Lipid peroxidation measured as MDA levels decreased significantly [F (9, 90) = 6.19, $P < 0.001$] with SILY 140, SILY 280, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, while an increase was observed with DEX, DEX/SERT, and DEX/SILY 140 compared to the vehicle control. Compared to SERT alone, there was a significant decrease in MDA levels with SILY 140 and SILY 280. While compared to DEX, there was a decrease with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was a decrease in MDA levels with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone or co-administered with SERT decreased lipid peroxidation levels.

Effect of silymarin on brain levels of inflammatory markers, acetylcholinesterase activity, lipid peroxidation, and antioxidant status

Table 2 shows the effect of SILY on brain (hippocampus and cerebral cortex) levels of inflammatory markers (TNF-α and IL-10), acetylcholinesterase activity, lipid peroxidation, and antioxidant status. Brain (hippocampus and cerebral cortex) levels of TNF-α [F (9, 90) = 65.12, $P < 0.001$] decreased significantly with SERT, SILY 140, SILY 280, DEX, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase in brain (hippocampus and cerebral cortex) levels of TNF-α with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was an increase in brain levels of TNF-α with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY administered alone decreased TNF-α levels, and when given alone or co-administered with SERT, it mitigated DEX-induced alterations in TNF-α levels.

Brain (hippocampus and cerebral cortex) levels of IL-10 [F (9, 90) = 22.36, $P < 0.001$] decreased significantly with SERT, DEX, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase in brain levels of IL-10 with DEX/SILY and DEX/SERT/SILY at 140 and 280 mg/kg of feed, respectively. Compared with the group administered with DEX/SERT, there was an increase in brain levels of IL-10 with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY increased IL-10 Levels; alone or co-administered with SERT, it mitigated DEX-induced alteration in IL-10 Levels.

Table 2 Brain levels of inflammatory markers, acetylcholinesterase activity, lipid peroxidation, and antioxidant status

Group	TNF-α ng/g/protein	IL-10 pg/mg/protein	ACHe nmol/mg	MDA nmol/g/protein	GSH nmol/mg/protein	GPx mU/mg/protein
Control	38.78 ± 0.20	23.89 ± 0.20	32.10 ± 1.30	7.95 ± 0.50	0.75 ± 0.10	18.68 ± 1.10
SERT	24.12 ± 0.10[a]	19.20 ± 0.16[a]	28.19 ± 1.03[a]	8.01 ± 0.51	0.73 ± 0.11	17.60 ± 1.01
SILY 140	34.18 ± 0.10[a]	23.65 ± 0.20	24.22 ± 1.15[a,b]	6.91 ± 0.70[a]	0.92 ± 0.05[a,b]	34.54 ± 0.44[a,b]
SILY 280	33.11 ± 0.20[a]	23.80 ± 0.30	20.18 ± 1.15[a,b]	5.83 ± 0.63[a,b]	1.23 ± 0.05[a,b]	46.20 ± 0.54[a,b]
DEX	18.78 ± 0.13[a]	9.07 ± 0.10[a]	52.10 ± 1.25[a]	18.20 ± 0.56[a]	0.30 ± 0.05[a]	10.15 ± 0.80[a]
DEX/SERT	19.40 ± 0.10[a,c]	8.21 ± 0.19[a]	42.30 ± 1.11[a,c]	18.25 ± 0.76[a,c]	0.32 ± 0.02[a]	9.89 ± 0.80[c]
DEX/SILY 140	25.22 ± 0.11[c,d]	15.22 ± 0.20[c,d]	33.22 ± 1.24[c,d]	7.60 ± 0.80[c,d]	0.64 ± 0.03[a,c]	12.40 ± 0.83[a,c,d]
DEX/SILY 280	29.00 ± 0.12[a,c,d]	19.21 ± 0.23[c,d]	30.17 ± 1.13[a,c,d]	6.57 ± 0.63[a,c,d]	0.88 ± 0.03[c,d]	14.35 ± 0.07[a,c,d]
DEX/SERT/SILY 140	23.23 ± 0.10[a,c,d]	14.10 ± 0.12[a,c,d]	28.12 ± 1.21[c,d]	6.38 ± 0.61[a,c,d]	0.78 ± 0.01[a,c,d]	13.42 ± 0.71[a,c,d]
DEX/SERT/SILY 280	25.12 ± 0.10[a,c,d]	16.19 ± 0.15[a,c,d]	24.20 ± 1.10[a,c,d]	6.32 ± 0.50[a,c,d]	0.88 ± 0.03[a,c,d]	15.42 ± 0.89[a,c,d]

Values are expressed as the mean ± SEM.

[a]$P < 0.05$ *vs* control.

[b]$P < 0.05$ *vs* SERT.

[c]$P < 0.05$ *vs* DEX.

[d]$P < 0.05$ *vs* DEX/SERT. GPx: Glutathione peroxidase; MDA: Malondialdehyde; SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment.

Brain (hippocampus and cerebral cortex) acetylcholinesterase activity decreased significantly [F (9, 90) = 10.21, $P < 0.001$] with SERT, SILY 140, SILY 280, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and increased acetylcholinesterase activity with DEX and DEX/SERT compared to the vehicle control. Compared to SERT alone, there was a significant decrease in brain acetylcholinesterase activity with SILY 140 and SILY 280. While compared to DEX, a significant decrease in brain acetylcholinesterase activity was observed with DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was a decrease in brain acetylcholinesterase activity with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY decreased acetylcholinesterase activity; alone or co-administered with SERT, it mitigated DEX-induced alteration in acetylcholinesterase activity.

Brain (hippocampus and cerebral cortex) MDA levels decreased significantly [F (9, 90) = 10.21, $P < 0.001$] with SILY 140, SILY 280, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, and increased with DEX and DEX/SERT compared to the vehicle control. Compared to SERT alone, there was a significant decrease with SILY 140 and SILY 280. While compared to DEX, there was a decrease in brain MDA levels with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was a decrease in MDA levels with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY decreased MDA levels; alone or co-administered with SERT, it mitigated DEX-induced alteration in MDA levels.

Brain (hippocampus and cerebral cortex) levels of GSH [F (9, 90) = 5.12, $P < 0.001$] increased significantly with SILY 140, SILY 280, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280 and decreased with DEX, DEX/SERT, and DEX/SILY 140 compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was an increase in GSH with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280.

GPx activity [F (9, 90) = 6.27, $P < 0.001$] increased significantly with SILY 140 and SILY 280 and decreased with DEX, DEX/SERT, DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280, compared to the vehicle control. Compared to SERT alone, there was a significant increase with SILY 140 and SILY 280. While compared to DEX, there was a decrease with DEX/SERT and an increase with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Compared with the group administered with DEX/SERT, there was an increase in GPx with DEX/SILY 140, DEX/SILY 280, DEX/SERT/SILY 140, and DEX/SERT/SILY 280. Overall, the results showed that SILY increased GPx and GSH activity; alone or co-administered with SERT, it mitigated DEX-induced alterations in GPx and GSH activity.

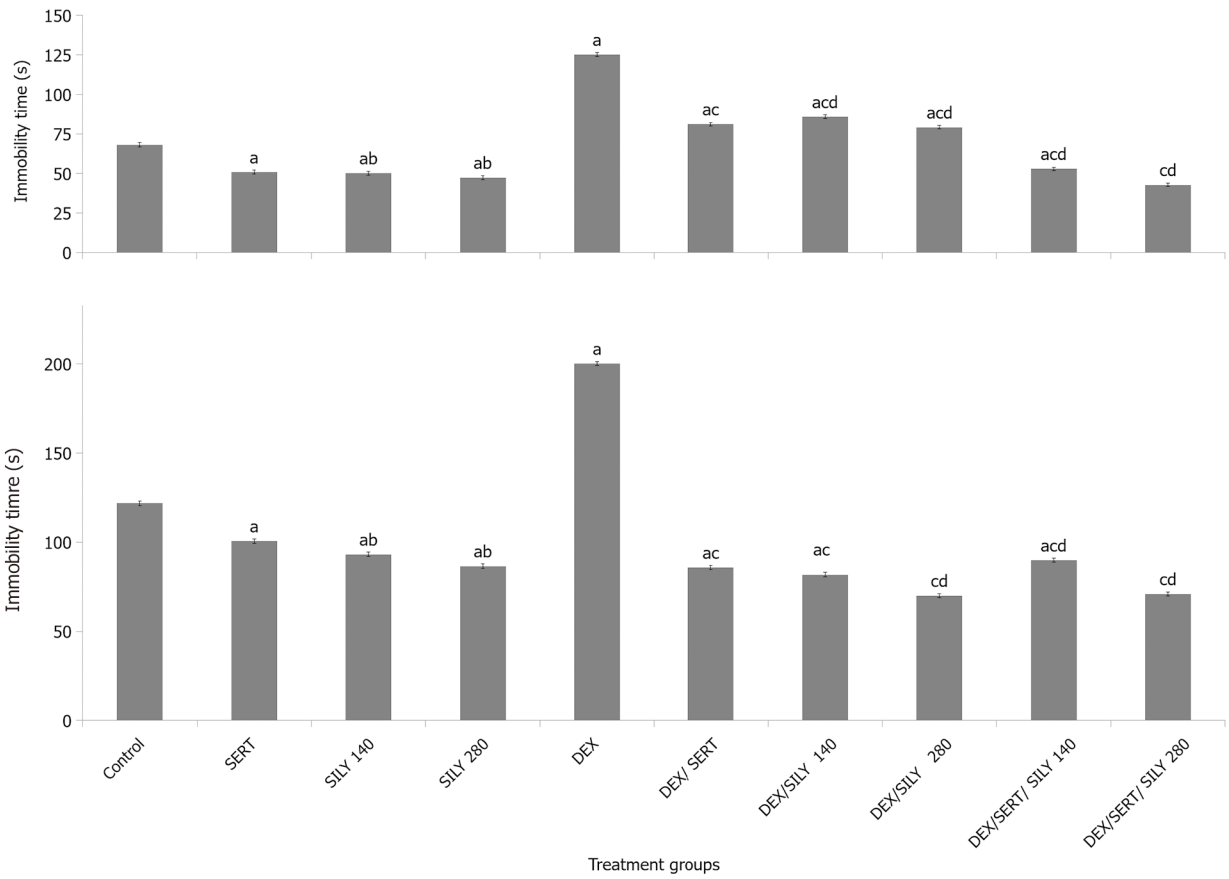

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Figure 7 Effect of silymarin on immobility time in the tail suspension (upper panel) and forced swim (lower panel) tests. Each bar represents the mean ± SEM, [a]*P* < 0.05 *vs* control, [b]*P* < 0.05 *vs* SERT, [c]*P* < 0.05 *vs* DEX, [d]*P* < 0.05 *vs* DEX/SERT. SERT: Sertraline; DEX: Dexamethasone; SILY: Silymarin. Number of mice per treatment group = 10.

Effect of silymarin on cerebral cortex and hippocampal morphology

Figure 8 shows representative photomicrographs of haematoxylin and eosin stained sections of the mouse cerebral cortex. Examination of the cerebral cortex sections of mice in the vehicle control group revealed characteristic architecture of the mouse cerebral cortex showing multipolar shaped pyramidal cells with rounded vesicular nuclei, granule cells visible as circular shaped neurons with large open-face nuclei, prominent nucleoli, and scanty cytoplasm and small round-vesicular shaped glial neurons interspersed within a pink-staining neuropil. These features are in keeping with normal cerebral cortex histology. Examination of the cerebral cortex sections of the SERT, SILY 140, and SILY 280 revealed features that were in keeping with normal histology. In the group administered with DEX, there was evidence of normal pyramidal cells with deeply stained nuclei, interspersed between degenerating pyramidal cells with pale edges, shrunken and pale staining nuclei. There was also evidence of degenerating granule cells with pale staining pyknotic nuclei. These features are in keeping with neuronal injury.

Examination of sections from groups administered with DEX/SERT, DEX/SILY 140, and DEX/SILY 280 revealed presence of normal looking cells and few degenerating pyramidal/granule cells. The features are in keeping with varying degrees of protection against the development of DEX-induced neuronal injury. In the groups administered with DEX/SERT/SILY 140 and DEX/SERT/SILY 280, the features were in keeping with normal cerebral cortex histology.

Figure 9 shows representative photomicrographs of haematoxylin and eosin stained sections of the dentate gyrus of the mouse hippocampus. Examination of the dentate gyrus region of the hippocampus in the vehicle control group revealed characteristic architecture of the mouse hippocampus with a few large multipolar pyramidal cells of the cornus ammonis 4 region projecting into the concavity of the dentate gyrus. Also observed were well-compacted small granule cells with vesicular nuclei in the ascending and descending arms of the dentate gyrus. Also obvious were astrocytes and microglia, neuronal processes, and nerve cells scattered throughout the molecular layer, that is, lying between the compact zones of the cornus ammonis and dentate gyrus regions. All features are in keeping with normal hippocampal dentate gyrus histology. Examination of the hippocampal dentate gyrus sections of groups fed SERT, SILY 140, and SILY 280 revealed features that were also in keeping with normal

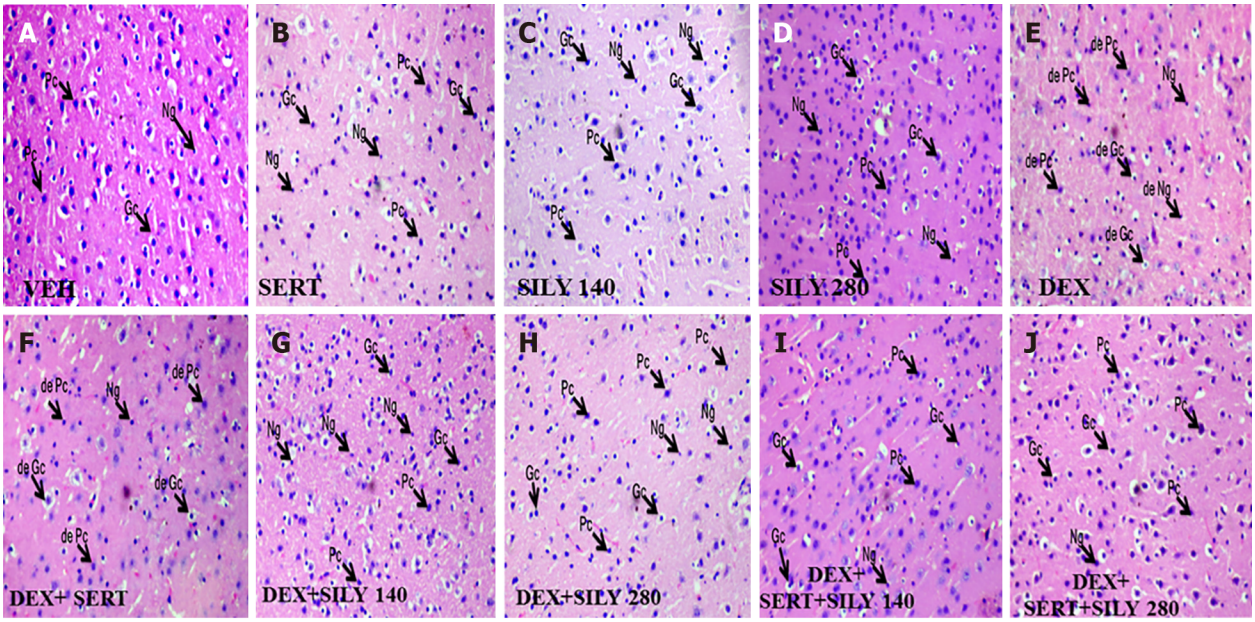

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Figure 8 Effect of silymarin on histomorphology of the cerebral cortex. Photomicrographs show pyramidal cells, granule cells, and neuroglia. A: Vehicle; B: Sertraline C: Silymarin at 140mg/kg of food; D: Silymarin at 280 mg/kg of food; E: Dexamethasone, F: Dexamethasone and sertraline G: Dexamethasone and silymarin at 140; H: Dexamethasone and silymarin at 280; I: Dexamethasone, sertraline and silymarin at 140; J: Dexamethasone, sertraline and silymarin at 280. de-Pc: Degenerating pyramidal cells; de- Gc: Degenerating granule cells; de-Ng: Degenerating neuroglia; Gc: Granule cells; Pc: Pyramidal cells; Ng: Neuroglia. Number of mice per treatment group = 5.

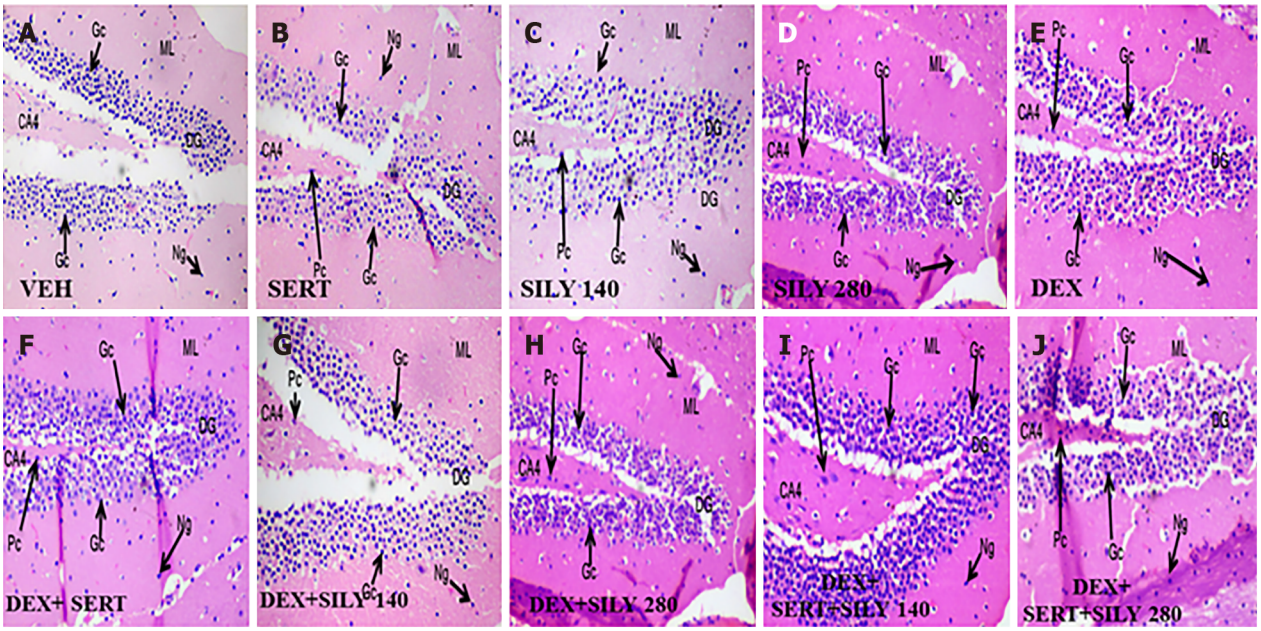

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Figure 9 Effect of silymarin on histomorphology of the dentate gyrus of the hippocampus. Photomicrographs show small pyramidal cells, small granule cells within the dentate gyrus proper, and neuroglia scattered within the molecular layer. A: Vehicle; B: Sertraline; C: Silymarin at 140mg/kg of food; D: Silymarin at 280 mg/kg of food E: Dexamethasone; F: Dexamethasone and sertraline; G: Dexamethasone and silymarin at 140; H: Dexamethasone and silymarin at 280; I: Dexamethasone, sertraline and silymarin at 140; J: Dexamethasone, sertraline and silymarin at 280. Gc: Granule cells; Pc: Pyramidal cells; Ng: Neuroglia; ML: Molecular layer. Number of mice per treatment group = 5.

histology. In the group administered with DEX, there were a few normal small pyramidal neurons interspersed between few degenerating pyramidal cells with pale edges, and there was also a paucity of cells in the molecular layer and loss of compactness of the granule cells in the dentate gyrus. Also observed were a few degenerating granule cells with pale staining nuclei; the features are in keeping with some neuronal injury.

Examination of sections from groups administered with DEX/SERT, DEX/SILY 140, and DEX/SILY 280 revealed presence of normal looking cells and few degenerating granule cells features, which are in keeping with varying degrees of protection against the development of DEX-induced neuronal injury. In the groups administered with DEX/SERT/SILY 140 and DEX/ SERT/SILY 280, the features are in keeping with normal dentate gyrus histology.

DISCUSSION

This study examined the antidepressant-like effects of SILY and SILY/SERT combination in mice to ascertain the role of SILY either alone or as an adjunct to SERT in mitigating DEX-induced behavioural and morphological changes in mice. The results showed that SILY administered alone increased body weight without altering food intake, increased open field locomotor activity, rearing, and grooming, enhanced spatial working memory, and decreased both anxiety-related behaviours and behavioural despair (immobility time in the forced swim and tail suspension tests). This was accompanied by an improvement in antioxidant status, and a decrease in lipid peroxidation, acetylcholinesterase activity, and inflammatory markers. Also, when administered alone or co-administered with SERT, SILY mitigated DEX-induced behavioural, biochemical, and morphological changes in relation to the cerebral cortex and hippocampus.

The impact of body weight and food intake on health, wellbeing, and disease has been reported[59,60]. In this study, administration of DEX was associated with significant weight loss and decreased food intake. While depression is generally associated with excessive weight gain, which has been linked to bingeing on food, according to the *Diagnostic and Statistical Manual of Mental Disorders,* both weight gain and weight loss are symptoms of depression at all ages[2,61]. Similarly, the choice of DEX as a model of depression is centred on its ability to cause dose-dependent weight changes[62,63]. At doses similar to those used in this study, DEX had been associated with weight loss[63], corroborating the results of this study. The results of a study by Poggioli *et al*[64] revealed that chronic administration of DEX was associated with decreased weight gain, which was attributed to its ability to accelerate fatty acid oxidation, and decrease brown adipose tissue thermogenesis and the activity of uncoupling protein-1 mRNA[64]. Weight loss could also be attributed to decreased feed intake which could be secondary to early satiety. The administration of SERT to healthy mice caused a decrease in weight gain without impacting feed intake when compared to mice in the vehicle control group, while increased weight loss was observed in the group of animals administered with SERT with DEX. While there is a dearth of scientific information on the impact of SERT in healthy subjects, it is, however, generally believed that selective serotonin re-uptake inhibitors like SERT are associated with weight gain. The results of a few studies have linked weight gain mainly to long-term use of SERT[65,66]; however, some clinical studies have reported reduced weight gain or weight loss following acute use of SERT in persons with depression[67]. The results of a preclinical study that examined the effect of SERT on body weight parameters in monkeys administered with SERT over an 18 mo period using a placebo-controlled, longitudinal, randomized study design showed that while the body weight and body fat composition of the placebo group increased, a decrease in body weight and fat composition was observed in the SERT treatment group[68]. In the groups of mice fed SILY alone, an increase in weight with no change in food intake was observed compared to mice in the vehicle control group. Also, in mice fed SILY with DEX, a reversal of DEX-induced weight loss was observed. Information from the current literature reveals that the vast majority of studies evaluating the effects of SILY on body weight have administered it in a background of disease or disorder[28,32,69-71]. The results of these studies have shown that administration of SILY could be associated with either weight loss or weight gain[28,32,69-71] depending on the disease model used. This would suggest that the effects of SILY on body weight are mainly modulatory or adaptogenic, having the ability to return the body back to baseline. The administration of SILY with SERT was also associated with a reversal of weight loss due to DEX-induced depressive symptoms, suggesting that compared to SERT, SILY could be beneficial in modulating the effects of SERT on body weight. However, the co-administration of SERT with SILY also in a background of DEX was associated with increased food intake compared to either SILY or SERT.

In this study, neurobehavioural tests revealed that administration of DEX was associated with a decrease in horizontal locomotion, rearing, and grooming behaviour, which is consistent with the observations of Falade *et al*[40]. The chronic unpredictable stress model was also associated with similar neurobehavioural changes[55]. The decrease in locomotor activity, rearing, and grooming is reflective of a central nervous system depressant response to DEX administration. Treatment with SERT was associated with a mitigation of the central depressant effect induced by DEX, although when administered to healthy mice, SERT did not significantly alter horizontal locomotion, rearing, or grooming, which is similar to the response observed by Pereira-Figueiredo *et al*[72]. In healthy mice fed a SILY diet, a central excitatory response was observed at 140 mg/kg. SILY alone or co-administered with SERT reduced the changes in locomotor activity, rearing, and grooming observed in mice administered with DEX alone. The concentration-dependent increase in locomotor activity, rearing, and grooming that occurred in healthy and DEX-treated mice could be linked to its ability to increase brain

levels of serotonin, dopamine, and norepinephrine, neurotransmitters that modulate central excitatory response in the brain[73-76]. Also, the co-administration of SILY with SERT was associated with a significant decrease in line crossing and an increase in grooming, with no significant difference in rearing behaviour compared with mice administered with SERT alone, suggesting that SILY could amplify the effects of SERT.

The neuroprotective effects of SILY have been reported[28,29,77-79] with a number of studies reporting its ability to reverse cognitive deficits and anxiety-related behaviours[79]. In this study, DEX was associated with spatial working memory deficits (Y-maze and radial arm maze) and anxiogenic response in the elevated plus maze paradigm. In past times, cognitive deficits were not considered an important part of depression symptomatology, so little or no attention was paid to cognitive disorders associated with depression. However, in the light of recent knowledge, researchers now know that cognitive symptoms could significantly impact general functioning and quality of life, and risk of recurrence of depression in these individuals[80]. The results of this study demonstrated that while SERT administration was associated with anxiolysis when administered alone or to DEX-treated mice, it showed no nootropic ability in healthy mice. Although it counteracted DEX-induced spatial memory deficits, the results observed with SERT in healthy mice corroborate the report of a study by Siepmann *et al*[81] that showed that in healthy humans, SERT was not associated with cognitive deficits or improvements in cognition. Although SERT reversed memory deficits in DEX-treated mice, studies in humans have reported that a selective serotonin reuptake inhibitor such as SERT was associated with memory loss and anxiety in persons with depression[82]. In groups fed SILY-supplemented diet alone, memory enhancing and anxiolytic effects were observed in both healthy and DEX-treated mice. This effect is similar to that observed by Yön *et al*[79] in diabetic rats. A number of other studies have also reported the ability of SILY to reverse cognitive deficits following scopolamine-induced amnesia[83] or mild traumatic brain injury[84], and these beneficial effects have been linked to its ability to decrease oxidative stress, inflammatory markers, and brain glutamate level, as well as increase antioxidant status and brain-derived neurotrophic factor in rodents[83,84]. Although compared to SERT, the administration of SILY to DEX-treated mice was associated within reversal of memory deficits suggesting that as a sole or replacement therapy it could provide some benefits, large clinical studies are required to confirm these in humans. When co-administered with SERT, memory and anxiolytic effects improved significantly compared to DEX-treated group administered with SERT, and these suggest that SILY could also be beneficial as an adjunct with SERT in depression management.

In this study, administration of SERT or a SILY-supplemented diet was associated with a decrease in immobility time in the behavioural despair paradigm in healthy animals, while DEX caused increased immobility time compared to healthy controls. Several studies have reported that chronic administration of DEX in humans and experimental animals was associated with the development of mood disorders including psychosis and depression[40,85,86]. The ability of DEX to increase immobility time has also been reported by other studies[40,87,88]. However, there is an increasing need for animal models of depression other than the currently available models of behavioural despair (forced swim test and tail suspension test). Animal models such as the one employed in this study supports the glucocorticoid hypothesis of depression[89] and would be valuable in the testing of novel drugs for the management of depression. In this study, chronic DEX administration was associated with weight loss, decreased food intake, locomotor retardation, cognitive deficits, anxiety, and behavioural despair, and a number of these symptoms and signs are necessary for the diagnosis of depression in humans. The mitigation of a number of features by SERT (a conventional antidepressant) supports the face and predictive validity for its possible use as a preliminary method for studying novel pharmacologic agents with possible antidepressant effects. A limitation of this study is our inability to assess plasma or brain glucocorticoid levels. SILY supplementation alone or co-administered with SERT in this study was associated with the reversal of DEX-induced behavioural despair. The antidepressant effects of SILY have been reported especially in studies that used acute restraint stress[76], the chronic unpredictable stress model of depression[90] or posttraumatic stress disorder[91]. In both behavioural despair paradigms, the antidepressant effects of SERT increased significantly with SILY at a concentration of 280 mg/kg of feed, although it decreased at 140 mg/kg of feed, suggesting that high concentrations of SILY could elicit an additive beneficial effect.

The antidepressant, memory enhancing, and anxiolytic effects of SILY have been attributed to its ability to decrease oxidative stress, improve antioxidant status, and increase antiinflammatory markers [76,90]. In this study, dietary SILY supplementation was associated with a mitigation of DEX-induced changes in brain oxidative stress, antioxidant status, and inflammatory markers. It also counteracted DEX-induced increase in acetylcholinesterase activity which could also be responsible for the memory enhancing effects of SILY. When SILY was co-administered with SERT, we observed significant improvements in the oxidant antioxidant balance, and an antiinflammatory response over the effects observed with SERT alone, also reinforcing our opinion that SILY when examined in a rodent model of depression exhibited both adjunctive and sole therapeutic benefits.

Structural and morphological changes have been reported in humans with depression[92,93]. In this study, the administration of DEX resulted in neuronal injury in the cerebral cortex and hippocampal dentate gyrus, two regions of the brain which have been implicated in depression[92-94]. In this study, SERT and SILY-supplemented diet at both concentrations mitigated the structural changes induced by

DEX. The co-administration of SERT with SILY showed marked mitigation of these changes, suggesting that SILY was not only beneficial when administered alone, but it also possibly accentuated the effects of SERT. While our knowledge of the structural and morphological changes in depression and how they impact pathogenesis and treatment are still evolving, it is important to realise that the use of supplements such as SILY that have validated adaptogenic, antioxidant, antiinflammatory, cognitive enhancing, anxiolytic, and neuroprotective effects could be valuable in depression management, although clinical studies and trials would be necessary to verify its usability in humans.

CONCLUSION

The ability of SILY to modulate behaviour, oxidative stress, and neuroinflammation makes it a possible monotherapeutic agent or an adjunct in the management of DEX-induced depression. In this era when clinical management of depression has continued to be challenging, the discovery and application of such an agent are likely to be of benefit in at least a certain subset of patients. The value of an agent such as SILY is likely to rest in the fact that it can employ mechanisms of action that go beyond neurotransmitter modulation.

ARTICLE HIGHLIGHTS

Research background

Depression is a neuropsychiatric disorder that has in recent times become a leading cause of disability and a major contributor to global disease burden and suicide.

Research motivation

There is increasing advocacy for the use of herbal supplements in depression management.

Research objectives

To determine the effect of silymarin dietary supplements alone or in combination with sertraline in a mouse model of depression.

Research methods

Preclinical study.

Research results

Silymarin mitigated dexamethasone-induced central nervous system changes in mice.

Research conclusions

Silymarin could have a place in the management of depression in humans.

Research perspectives

Further studies should be performed to examine the possible effects of silymarin in humans with depression.

FOOTNOTES

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