Antineoplastic activity of a methanolic extract from Kigelia pinnata DC stem bark

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Abstract

Background: The study was aimed to assess the antineoplastic activity of a total methanolic extract (TME) from the stem bark of Kigelia pinnata - an African medicinal plant with well-documented ethnopharmacological use.

Methods: The in vitro testing included cytotoxicity (MTT assay) and pro-apoptotic activity investigation. The antineoplastic activity of TME was investigated in Lewis lung carcinoma (LLC) bearing BDF-1 mice.

Results: TME displayed prominent cytotoxicity against a panel of human tumor cell lines. TME evoked DNA laddering in SKW-3 cells, indicative for induction of apoptosis. TME exerted strong antineoplastic activity against LLC with prominent increase of the life span of treated animals and tumor growth inhibition.

Conclusion: On the basis of the in vitro studies and the observed in vivo antineoplastic potential of the plant it could be concluded that there is enormous scope for future investigations on K. africana as a source of potential anticancer agents.

Keywords: Kigelia africana, plant extracts, MTT-assay, cell lines, cytotoxicity, apoptosis, Lewis lung carcinoma.

Background

At present plant-derived cytotoxic drugs (e.g. the Vinca alkaloids, epipodophyllotoxins, camptothecins and taxanes) play a key role in antineoplastic drug therapy and a number of other phytochemicals are subjected to clinical trials [1-6]. Moreover, the unfavorable safety profile of existing chemotherapeutics and the issue of drug resistance have fuelled the search for novel plant compounds as potential anti-cancer agents [7,8]. In addition to the systematic large-scale screening of unexplored plant species [9] and the phytochemically-guided search of molecules which are structurally related to established antineoplastic drugs [10], the other possible approach for identifying perspective drug candidates is based on ethnopharmacology, i.e. scientific study of traditional plant remedies [7,11]. Such studies have received further impact due to introduction of high-throughput screening techniques and improved methods for extraction, isolation and structural elucidation of biologically active compounds [4-6,9,12]. In recent years ethnopharmacological studies of extracts or pure compounds from medicinal plants have provided considerable justification for their traditional use to treat neoplastic diseases [7,8,11].

Kigelia pinnata DC (or K. africana), Bignoniaceae family, also known as Sausage Tree, or Worsboom, in view to its bulky, characteristically shaped fruits, has a variety of traditional medicinal uses throughout Africa where it grows as an endemic species in different habitats [13,14], as well as in India and the Middle East whereby the tree has been widely cultivated [15,16]. The extensive phytochemical examinations of the plant has resulted in the isolation of different secondary metabolites such as iridoids [17-19] and naphthoquinoids [20-24], considered to convey much of its pharmacological activities [13], although flavonoids, lignans, terpenoids, coumarins, phenylethanoids, phenylpropanoids and sterols have been isolated, as well [14,24,25].

Much of the studies on the biological activity of Kigelia pinnata have been concentrated on its antimicrobial effects [17,24] and its cytotoxicity against cancer cell lines [20-22]. This research interest is related to the traditional uses of bark and fruit extracts throughout Africa as remedies for treating sexually transmitted diseases, dysentery, leprosy, miscellaneous microbial and parasitic infections, skin ulcers, and neoplastic diseases [13,14,16,26]. Moreover, extracts from the plant, as well as isolated compounds, have been found to exert a constellation of other pharmacological effects, including antifungal [24], antiprotozoal (against Trypanosoma brucei brucei, Trypanosoma brucei rhodesiensc [23], and several, including
multi-drug resistant, strains of Plasmodium falciparum [27-29]),
antinflammatory and analgesic [15,19], hepatoprotective [30],
anti-fertility [31], CNS-stimulant, anti diarrheal, and anti diabetic
[13,14,32], among others.
Pharmacological studies regarding the antineoplastic
totality of the plant were fuelled by anecdotal reports
for the traditional use of fruit and stem bark extracts by
indigenous Africans and by white settlers for the treatment
of melanoma and other skin neoplasms [13], as well as for the
management of endometrial cancer [14], and hence much
of the experimental chemotherapy research was focused
on solid tumor-derived cell lines [20-22,33]. Studies were
initiated testing ethanol and dichloromethane extracts from
Kigelia pinnata fruit and stem bark for cytotoxicity against
melanoma and renal carcinoma derived cell lines [20-22]. By
means of bioactivity-guided fractionation it has been found
that the extracts contain various cytotoxic agents, such as
lapachol (regarded as a potential anti-cancer drug [34]),
norviburtinal [22], kigelinone, and γ-sitosterol [16] among
others. Nevertheless, the relative contribution of every different
compound to the observed activity of the extracts remains
elusive, because some of these (e.g. norviburtinal and lapachol)
are present in the plant materials at very low concentration
to be main responsible anti-cancer constituents, while the
cytotoxicity of others, such as γ-sitosterol has remained an
issue of debate [13,14,22].
Considering the scarce data about the efficacy of Kigelia
pinnata against hematological malignancies and the lack of
evidence for in vivo antineoplastic activity in the available
literature we sought to determine the anticancer potential
of a stem bark methanolic extract in a panel of human tumor
cell lines, including leukemia and lymphoma derived cells,
and to evaluate its efficacy against Lewis lung carcinoma,
transplanted s.c. in BDF-1 mice, in terms of tumor growth
inhibition and increase in life span.
Methods
Drugs, chemicals and reagents. Formic acid, 2-propanol,
L-glutamine and ethidium bromide were purchased from
AppliChem GmbH, Darmstadt, Germany. Fetal calf serum (FCS)
and RPMI 1640 medium were purchased from Sigma – Aldrich
Co., the USA. The tetrazolium salt 3-(4,5-dimethylthiazol-2-yl)–
2,5-diphenyl tetrazolium bromide (MTT) was supplied from Merck
Co., Germany. The referent antineoplastic drug vincristine
was used as a commercially available sterile dosage form for
clinical application.
Plant material, extract preparation, fractionation and
formulation. Dried Kigelia pinnata stem bark was supplied from
a licensed Nigerian wholesaler with the kind assistance
of Mr. A.-H. T. Sahinnna. The plant material was identified by
Asst. Prof. P. Nedialkov and Asst. Prof. D. Zheleva and a
voucher specimen was deposited at the Herbarium of the
Dept. of Pharmacognosy and Pharmaceutical Botany at the
Faculty of Pharmacy (MU-Sofia) (No 17/2010). The powdered
(1 mm) stem bark was refluxed with methanol (1: 20) for 1 h
at 80°C. After cooling at room temperature the extract was
filtered and the residue was subject to the same extraction
process twice. Thereafter the filtrates were gathered and
the solvent was evaporated in vacuo to dryness. The so
prepared total methanolic extract (TME) was either used
for the pharmacological studies or subjected to column
chromatography fractionation.
For further processing of the so prepared total extract (for
the bioactivity guided fractionation) it was dissolved in MeOH
(1:3) and mixed with 1.0 Silicagel prior to chromatographic
assay. Equal quantities were subject to column chromatography,
under the following conditions – column with 50 cm length
and 1 cm diameter using Silicagel as adsorbent and the
following mobile phases: (i) chloroform; (ii) chloroform : ethyl
acetate (1:1); (iii) methanol : ethyl acetate (2:8); (iv) methanol :
ethyl acetate (1:1); (v) methanol : ethyl acetate (8:2); (vi)
methanol. The eluates were chromatographed on pre-coated
plates of kieselgel G, using the following mobile phases for
developing the chromatograms: (i) 20% ethyl acetate in
cyclohexane; (ii) petrol ether: acetone: chloroform;
methanol (4:1:5:4:0.5); (iii) 50% ethylacetate in cyclohexane.
The solvents were evaporated in a warm air stream and
detection was with UV light at 254 and 366 nm. Based on
the chromatographic analysis eluates were combined in 10
poled fractions, and thereafter the solvent was removed with
a rotary evaporator. The TLC plates were also analyzed for
the presence of quinone derivatives using 10% KOH methanolic
solution as a spray reagent [36].
For the in vitro bioassay the extracts were freshly dissolved
in DMSO and thereafter promptly diluted with RPMI-1640
medium to yield the desired working concentrations. For the
in vivo experiments the total methanolic extract was freshly
dissolved in sterile saline at 36°C in a thermostat-supplemented
bath-type sonicator.
Cell lines and culture conditions. The study was carried
out with the following cell lines: (i) SKW-3 (ACC 53) – human
T-cell leukemia, originally described to be established from
the peripheral blood of a 61-year-old man with T cell
chronic lymphocytic leukemia (CLL) in 1977; however, DNA
fingerprinting and cytogenetic analysis showed cross-
contamination with cell line KE-37; KE-37 was established from
a 27-year-old man with acute lymphoblastic leukemia (ALL)
in 1979; (ii) REH (ACC 22) – human B-cell precursor leukemia,
established from the peripheral blood of a 15-year-old North
African girl with acute lymphoblastic leukemia (ALL at first
relapse) in 1973; carries t(12;21) leading to ETV6-RUNX1 (TEL-
AML1) fusion gene; (iii) HL-60 (ACC 3) - human acute myeloid
leukemia (AML), established from the peripheral blood of a
35-year-old woman with acute myeloid leukemia (AML FAB
M2) in 1976; cells are apparently tetraploid derivatives of the
hypodiploid original; (iv) K-562 (ACC 10) – human chronic
myeloid leukemia (CML) established from the pleural effusion
of a 53-year-old woman with CML in blast crisis in 1970; cells
were isolated from the cytosolic fraction of SKW-3 cells. Briefly, exponentially growing SKW-3 cells were exposed to bark total methanolic extract or vincristine for 24 h (untreated controls, and treated with *Kigelia pinnata* stem bark methanolic extract 37.5 mg/kg (i.p.; ×3); (ii) *Kigelia pinnata* saline - treated control group; (iii) *Kigelia pinnata* stem bark methanolic extract 75 mg/kg (i.p.; ×3); and (iv) *Kigelia pinnata* stem bark methanolic extract 105 mg/kg varying concentrations of the tested compounds after the treatment period. The cell viability after exposure to the tested compounds was normalized as percentage of the untreated control (set as 100% viability), were fitted to sigmoidal dose response curves and the corresponding IC50 values (concentrations causing 50% suppression of cellular viability) were calculated using non-linear regression analysis (GraphPad Prizm Software for PC). The statistical processing of biological data included the Student’s t-test whereby values of p ≤ 0.05 were considered as statistically significant. The in vivo data development is described in the corresponding section of the Materials and methods section.

In vivo studies (experimental design, treatment and assessment of the antineoplastic activity). Animal studies were approved by the Institutional Ethics and Animal Care Committee. Young adult male C57BL/6 and BDF-1 mice of 6 to 8 weeks old, weighing 21±2 g were purchased from the National Breeding Centre (Slivnitzia, Bulgaria). Animals were housed in the Animal Care Facility of the Faculty of Pharmacy, MU-Sofia with free access to water and standard pelleted food (Altromin Spezialfutter GmbH & Ko KG, Germany) with 12 h alternating light/dark cycles. The in vivo studies were carried out as described elsewhere [39]. In brief, Lewis Lung Carcinoma originally obtained from the Lab of Oncopharmacology at the National Oncological Hospital (Sofia Bulgaria), has been maintained in our facility by serial passages subcutaneously (s.c.) in inbred C57BL/6 mice since 1994. The tumor mass (2–3 g, 3–4 weeks old) was minced in 10 mL Hank’s solution and filtered through an 80-mesh screen with a 21-gauge needle. An aliquot (0.2 mL) of the tumor homogenate containing typically 2–4×106 viable tumor cells was inoculated subcutaneously (s.c.) into male BDF-1 mice, in the right flank. Mice were randomly divided into 4 groups (10 mice per group) as follows: (i) normal saline - treated control group; (ii) *Kigelia pinnata* stem bark methanolic extract 37.5 mg/kg (i.p.; ×3); (iii) *Kigelia pinnata* stem bark methanolic extract 75 mg/kg (i.p. ×3); and (iv) *Kigelia pinnata* stem bark methanolic extract 105 mg/kg.
(i.p.; ×3). Treatment was performed on days 1st, 5th and 9th post transplantation. Tumor size was determined by caliper measurement of the largest and perpendicular diameters on study days 6, 10 and 14. Tumor volume was calculated according to the formula \( V = 0.52 \times a \times b^2 \) (where \( a \) is the largest superficial diameter and \( b \) is the smallest superficial diameter). The tumor growth inhibition (TGI\%) was calculated using the following formula: 
\[
\text{TGI\%} = \left( \frac{V_T - V_C}{V_C} \right) \times 100,
\]
where \( V_T \) is the mean tumor volume in the treatment group and \( V_C \) is that of the control mice.

The survival of animals was monitored on daily basis until the completion of the experiment. Thereafter, Kaplan-Meier curves were generated and the median survival times were calculated using GraphPad Prizm software. Improvement in survival was evaluated as follows: 
\[
\text{ILS \%} = \left( \frac{T}{C} - 1 \right) \times 100,
\]
where ILS is the increase in life span, \( C \) is the median survival days of the control mice and \( T \) is that of the treated mice. According to NCI criteria ILS > 25% was set as threshold for activity, whereas treatment yielding ILS > 50% was considered highly active [40].

**Results**

The cytotoxic effects of *K. pinnata* stem bark total methanolic extract were evaluated in a panel of human tumor cell lines representative for some important neoplastic diseases namely acute lymphoid leukemia (SKW-3 and REH), acute myeloid leukemia (HL-60), chronic myeloid leukemia (K-562), B-cell lymphoma (DOHH-2), Hodgkin lymphoma (HD-MY-Z), ER-positive breast cancer (MCF-7) and murine lung cancer (Lewis lung cell line). In addition, the initial total extract was further subjected to a bioactivity guided fractionation (see below). The equieffective IC\(_{50}\) concentrations (the concentration leading to 50% reduction of the cellular viability) served as criteria for comparing the cytotoxic activity of the extract and its fractions. Throughout the cytotoxicity screening the clinically applied anticancer drug vincristine was employed as a positive control.

**Table 1.** Bioassay data regarding the cytotoxicity of Kigelia pinnata stem bark methanolic extract in a panel of human tumor cell lines. The equieffective IC\(_{50}\) concentrations were calculated from the experimental bioassay data using non-linear regression analysis (GraphPad Prizm software).

| Treatment | IC\(_{50}\) (µg/ml) | SKW-3\(^a\) | Reh\(^b\) | HL-60\(^c\) | K-562\(^d\) | DOHH-2\(^e\) | HD-MY-Z\(^f\) | MCF-7\(^g\) | LL\(^h\) |
|-----------|---------------------|--------------|-----------|------------|-----------|--------------|------------|-----------|--------|
| TME       | 15.1 ± 3.4          | 126.0 ± 9.1  | 90.7 ± 4.7| 186.0 ± 9.2| 101.0 ± 7.4| 124.1 ± 8.9 | 11.8 ± 3.8 | 10.2 ± 2.7 |
| CF3       | 148.1 ± 7.5         | n.d.         | n.d.      | n.d.       | n.d.      | n.d.         | n.d.       | n.d.      |
| CF7       | 150.6 ± 3.4         | n.d.         | n.d.      | n.d.       | n.d.      | n.d.         | n.d.       | n.d.      |
| Vincristine\(^*\) | 0.22 ± 0.1 | 3.3 ± 0.9   | 1.5 ± 0.7 | 4.1 ± 1.4 | 1.2 ± 0.6 | 7.4 ± 1.0   | 3.7 ± 0.6  | 2.2 ± 0.4  |

\(^a\) T-cell leukemia (a KE-37 derivative), \(^b\) acute lymphoid leukemia, \(^c\) acute myeloid leukemia, \(^d\) chronic myeloid leukemia, \(^e\) non-Hodgkin lymphoma, \(^f\) Hodgkin lymphoma, \(^g\) breast cancer; \(^h\) Lewis lung cell line – murine lung cancer; \(^*\) positive control.

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**Figure 1.** A. Cytotoxic effects of Kigelia pinnata stem bark (total methanolic extract (TME) and chloroform fractions CF3 and CF7) against SKW-3 cells after 72 h treatment. Each data point represents the arithmetic mean ± sd of eight separate experiments. B. DNA-laddering of the genomic DNA extracted from SKW-3 cells after exposure to Kigelia pinnata stem bark TME as assessed by 0.8% agarose gel electrophoresis, ethidium bromide staining and UV-transillumination. (1) DNA fragmentation marker; (2) untreated control; (3) Kigelia pinnata TME 300 µg/ml; (4) Kigelia pinnata TME 150 µg/ml; (5) Kigelia pinnata TME 75 µg/ml; (6) vincristine 0.5 µg/ml; (7) vincristine 1 µg/ml.
Table 2. In vivo antineoplastic activity of Kigelia pinnata stem bark methanolic extract against Lewis lung carcinoma, transplanted s.c. in BDF-1 mice as assessed by the increase in life span (ILS %) and tumor growth inhibition (TGI%) endpoints.

| Experimental group          | MST  | T/C % | ILS (%) | Long term survivors1 | 10th Day | 14th Day |
|----------------------------|------|-------|---------|----------------------|----------|----------|
| Control (saline ×3)        | 20.4 | N/A   | N/A     | 0                    | N/A      | N/A      |
| TME 37.5 mg/kg i.p. (×3)   | 30.2**| 148.0 | 48.0    | 1                    | 89.5     | 87.5     |
| TME 75 mg/kg i.p. (×3)     | 34.0**| 166.7 | 66.7    | 2                    | 80.7     | 79.8     |
| TME 100 mg/kg i.p. (×3)    | 33.7**| 165.2 | 65.2    | 1                    | 81.2     | 88.0     |

1Number of animals that have survived over 60 days; N/A-not applicable; *MST statistically significant (at p≤0.01) vs. the untreated control: p=0.0002 (37.5 mg/kg), p = 0.0044 (75 mg/kg), p = 0.0105 (100 mg/kg) (log-rank test).

in order to allow identification of sub-fractions possessing biological activity. With the only exception of chloroform fractions CF3 and CF7 (Figure 1), all other fractions were devoid of cytotoxic activity (less than 20% inhibition at the highest concentration applied (300 μg/ml); data not shown). Both active fractions however, were significantly less active as compared to the total methanolic extract of the plant, whereby the IC50 values obtained were practically 10 times higher. Thus facing the obvious loss of activity upon fractionation the other pharmacological investigations (i.e. apoptosis detection and in vivo antineoplastic activity) were carried out with the parent methanolic extract.

A TLC analysis was conducted aiming to establish the chromatographic profile of the pharmacologically active crude extracts and its CF3 and CF7 fractions. The analysis of the active extracts showed zones of green color at retention factor (Rf) 0.12-0.13 a blue zone at 0.31 and 0.23, and pink areas at 0.44 Rf both in crude extract and in chloroform fractions CF3 and CF7. When the chromatogram was observed under ultraviolet light at 254 nm, three absorption zones were observed with the following retention factor (Rf) 0.12, 0.23, 0.31 and 0.44, respectively. The chromatograms, after treatment with a 10% KOH methanolic solution - a well established spray reagent to detect quinones in the sample, showed brownish colored zones at Rf 0.23, 0.31 and 0.44 when observed under day light. These findings indicate the presence of quinone compounds. The ability of the total methanolic extract of Kigelia pinnata to induce apoptotic cell death was investigated by means of gel electrophoresis of DNA, extracted from the cytosolic fractions of SKW-3 after 24 h exposure at 75, 150 or 300 μg/ml. The image obtained after DNA electrophoresis, ethidium bromide staining and UV-transillumination (Figure 1) shows the formations of detectable oligonucleosomal DNA laddering, indicative for execution of the apoptotic cascade.

The Kaplan-Meier survival curves and the corresponding values of the median survival time (MST) and increase in life span (ILS) are reported in Figure 2 and Table 2 respectively. The control mice exhibited a mean survival time of ca. 20 days. Evident from the results obtained the total methanolic extract from the stem bark of K. pinnata exerted strong antineoplastic activity in vivo, whereby the most prominent increase of the life span of treated animals (ca. 67% vs. the untreated control) was encountered at doses 75 mg/kg (66.67% vs. the untreated control) and 100 mg/kg (65.2 versus the untreated control).
The tumor growth inhibition (calculated from the tumor size monitoring on days 6, 10 and 14 after transplantation) was employed as a secondary end-point for the antineoplastic activity of the extract (Table 2, Figure 2). Statistically significant reduction in tumor size and volumes were found on days 10th and 14th all doses of the methanolic extract of the plant proved to hamper the enlargement of the tumor volume as compared to the untreated control, with TGI values ranging between ca. 80 and 90%.

Discussion

This study was commenced in an attempt to elucidate some of the generally unexplored aspects of the oncopharmacological properties of Kigelia pinnata and more precisely its efficacy against in vitro models of hematologic malignancies on one hand, and its in vivo tumor-inhibiting potential, on the other. To meet this objective a detailed cytotoxicity screening was performed in a panel of eight tumor cell lines after 72 h exposure using the MTT-dye reduction assay as a read-out system and the IC50 as an end-point to evaluate efficacy. The proven cytotoxic activity of the methanolic extract further supported the earlier findings regarding the effects of K. pinnata dichloromethane, ethanol or water extracts against human cancer cells [16,21,22]. The results unambiguously indicate that the cell lines are chemosensitive to the components of the crude extract, even though with varying degree. Generally the IC50 values were within the range of those previously published [13,20,22,41], albeit somewhat higher. These differences could be ascribed to the type of extract (e.g. fruit, bark, dichloromethane, ethanolic etc.) and to the peculiarities of the cell lines investigated. Much of the studies were focused on melanoma or other solid tumor-derived cell lines e.g. renal cell carcinoma [21], breast cancer [20], and colorectal carcinoma [33]. Nevertheless, the established difference in the chemosensitivity could not be solely ascribed to the cell type and origin of the models, but also to the experimental conditions employed. Thus most of the preceding studies used a substantially longer incubation period of 144 h [20-22] as compared to our experimental design with exposure for 72 h. Considering the fact that in vitro studies by-pass nearly all pharmacokinetic processes it could be easily concluded that 6 days long exposure could not adequately mimic the in vivo situation. It is noteworthy in this context that the NCI guidelines for cytotoxicity screening recommend a 48 h incubation period [40].

In general, albeit the number of cell lines is limited for broad and definitive conclusions to be drawn out, the study has shown that the leukemia- and lymphoma derived cell lines are less sensitive to K. pinnata as compared to the solid tumor models (MCF-7 and Lewis lung), the only exception being the acute T-cell leukemia SKW-3. The observed chemosensitivity of the ER-positive breast cancer derived cell line MCF-7, also noted in previous studies with fruit extracts [20], warrants for more detailed evaluation regarding possible hormonal effects of the extract ingredients, especially having into consideration the anti-implantation activity of an ethanolic extract of K. pinnata [31] and the traditional utility of the plant to alleviate breast swelling, tenderness and pain [14], which are indicative for possible ER-modulating activity.

Our effort to perform a bioactivity-guided fractionation using column chromatography led to the isolation of ten pooled fractions. Among these however, only methanolic fractions CF3 and CF7 retained biological activity, albeit sufficiently lower as compared to that of the crude extract. This well corroborates to the results from a previously described study whereby the fractionation of a highly cytotoxic chloroform extract of K. africana fruits was associated with a significant loss of activity in all of the nine obtained fractions. Even the most active fractions had their equitoxic IC50 values shifted to substantially higher concentrations [22]. Although such detrimental effects of fractionation could be due to decomposition or oxidation of the putative active principles during the separation process, they could well be a consequence of pharmacological synergy between the different components of the parent crude extract [41,42]. In fact the cytotoxicity of K. africana has been regarded as a typical example of synergy between the individual active principles, a phenomenon well established for various medicinal plants [42].

The performed phytochemical study has shown that the tested extract contains quinone species, to which its biological activity could be generally ascribed. Despite the immense pharmacological and phytochemical research on Kigelia pinnata the delineation of its real active principles remains elusive. Nevertheless, in general the anticancer and antiprotozoal activities have been attributed to the quinone compounds, especially the furanonaphthoquinoids characteristic for this species e.g. isopinnatal, kigelinole and isokigelinol, and kigeline [22,23,27,43], the latter being characterized as cytotoxic agent and identified in other plants used as traditional antineoplastic remedies [16,44]. Moreover, quinone structural fragment is found in some important anticancer drugs, or investigational cytotoxic agents including the anthracycline antibiotics, mitoxanthrone, aloe-emodin, lapachol (an identified constituent of K. africana) [21,35,45-48] etc.

Based on the lack of data regarding the mechanistic aspects of K. pinnata cytotoxicity we commenced a pharmacodynamic study on its ability to trigger oligonucleosomal DNA-fragmentation – a key hallmark of apoptosis. The observed DNA-laddering after a short term exposure of SKW-3 cells to the tested extract indicates that the cytotoxic effects of the active principles are at least partly mediated by induction of programmed cell death (apoptosis). This has been identified as a major mechanism for the cytotoxic mode of action of otherwise chemically and pharmacologically distinct classes of plant-derived antineoplastic agents [5,7,49].
The tested methanolic extract exhibited prominent antineoplastic activity against Lewis lung carcinoma s.c. transplanted in BDF-1 mice. It significantly suppressed the tumor growth and more importantly was associated with increase in life span of all treated groups as compared to the untreated control. The lack of treatment-related mortality and the long-term survivors in all treatment groups is indicative for both antineoplastic efficacy in this tumor model and good tolerability within the tested dose range. To the best of our knowledge, this is the first report on the in vivo tumor-inhibiting activity of K. pinnata extract.

Conclusions
Taken together our findings firmly indicate that K. pinnata stem bark extract is endowed by potent cytotoxic and antineoplastic effects, acting at least partly via apoptosis induction. Based on the in vitro studies and especially considering the observed in vivo tumor inhibiting potential of the plant it could be concluded that there is enormous scope for future detailed pharmacological as well as phytochemical investigations on K. africana as a natural source of potential antineoplastic agents.

Competing interests
The authors declare neither financial nor other competing interests.

Authors' contributions
DM carried out the phytochemical and pharmaceutical elaboration of the extract, participated in the bioactivity-guided fractionation, prepared the extract formulation for the in vivo study and took central role for the preparation of the manuscript. IP participated in the phytochemical and analytical studies. GM participated in the in vivo and in vitro bioassay design and conduction. SK participated in the design of the in vivo and in vitro studies, coordinated the project and helped to draft the manuscript and to compile the discussion of the results. All authors read and approved the final manuscript.

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