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Philological analysis of ancient Egyptian recipes supported by modern chemical profiling approaches

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ABSTRACT

Ethnopharmacological relevance: Ancient Egyptian sickness categories are poorly described, making it a challenge to correlate use of *materia medica* with sickness experience. Nevertheless, many identified ingredients are reported to have therapeutic potential, often used to support Egyptological interpretations of categories. Crucially, these interpretations fail to consider the impact of ancient processing methods.

Aims of study: We examine two sickness categories using traditional philological techniques, and then recreated and profiled three recipes to explore whether putative properties of principal components of the recipes were retained when ancient processing instructions were followed, to see if the results can further aid the philological analysis.

Methods: Philological analysis was lexicographical, following Egyptological standards. The recreated matter was analysed using nuclear magnetic resonance (NMR) spectroscopy to obtain a general overview of the compounds present. Subsequently, liquid chromatography-mass spectrometry (LC-MS) and gas chromatography-mass spectrometry (GC-MS) were conducted separately to provide additional insights on the compounds.

Results: A recipe using *H. vulgare* showed activities (hordenine) that corresponded to the sickness description and also that other recipe components had synergistic effects. The other two recipes demonstrated some correspondence with sickness categories also: *L. usitatissimum* showed limited anti-inflammatory properties for treating cough and *C. siliqua* epicatechin/gallate for treating cough and fever.

Conclusions: Ancient Egyptian pharmaceutical technologies contributed towards desired pharmacological effects, the compositum analysed indicated ingredient synergism from a modern perspective. Chemical profiling can support the philologist in commenting on the significance of processing practices, which can further aid understandings of ancient Egyptian sickness categories.

1. Introduction

Ancient Egyptian 'medical papyri' such as the Ebers Papyrus studied here (pEbers; *c.* 1530 BCE) are actually primarily composed of instructions for the creation of therapeutic 'recipes'. These recipes are formulaic, including only a named sickness and perhaps relevant area of the body only, before listing the ingredients, specified volumes thereof, and processing instructions (e.g., Westendorf, 1999, 80–95). These recipe compilations are therefore considered 'practice oriented' – that is, they were not intended to explain the Egyptians' perspectives of sickness nor therapy. This means that while in some parts of the text we do get short, fortunate glimpses into which sickness experiences/symptoms were grouped with which ancient categories of sickness/disease, much of this information was left unmentioned – presumably, as this information was implicit to the manuscripts' user, and did not need to be fully outlined in writing.

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This creates a significant problem for Egyptologists attempting to interpret ancient therapeutic practices. Cultures past and present develop unique terms for sickness experience and categorisations due to an untold number of influential social and cultural variables (e.g., Kleinman, 1980). The diversity and blurred boundaries between sickness categories, as what we can call a 'cultural domains', and the symptoms and therapeutics with which they are associated and which can characterise them, or 'domain members', are a challenge for foreign observers from modern cultures to elicit and define in the terms of their own language, such as English (e.g., Yoder, 1995; Weller and Romney, 1988; Borgatti, 1998; Ryan et al., 2000; Quinlan, 2019), not least as many of these domains overlap and blur (Olivier de Sardan, 1998; Steinert with Hsu, 2021).

Additionally, across cultures past and present, complex conceptual models have been used to explain healthy and sick states of the body – these are known as 'explanatory models'. These show a degree of variation grounded in 'idiosyncratic thought and circumstances', especially those concerned with inner-bodily function – notorious historical examples of the latter being those found in ancient sources, such as the Greco-Roman humours, Indian *doshas*, or the Chinese *yingyan and wuxing* (e.g., Leslie, 1976; Erickson, 2008; Horden, 2013; Quinlan, 2019, 2021). These explanatory models are of measurable consequence where therapy is concerned, as seen in the well-known use of bloodletting to rebalance humoral constitution in Greco-Arabic therapy or the administration of an epistaxis herbal preparation in Aztec medicine to cure headaches believed to be caused by blood-clots in the head (for the latter, see Oritz de Montellano, 1975; Browner et al., 1988).

Given their extreme age, any investigation into links between ancient Egyptian domains of sickness and the models used to explain them, as well as with the therapeutic applications used to treat them, is a challenge hampered on fronts beyond this issue. Beyond the stated issues of translatability of *materia medica* (Pommerening, 2016a, b; below), processing instructions for recipes have been pointed out as a valuable field of study for understanding potential pharmacological motives for including items in recipes (Pommerening, 2016b, 2017, 2023; Russell, 2024). Plants used in ancient Egypt as ingredients have been recognized for their continued therapeutic relevance in non-toxic doses today. Notable examples include: *Ziziphus spina Christi* (L.) Desf., *Balanites aegyptiaca* (L.) Delile, *Cuminum cyminum* L, *Punica granatum* L. (see e.g., Kadioglu et al., 2016; Kusch et al., 2011; Pommerening, 2006; Pommerening, 2017). More positivistic Egyptological approaches tend to cite only the known pharmacological properties reported in the scientific literature (most notably Germer, 2008). These overlook the impact of prescribed processing on these properties as, simply put, this crucial aspect falls beyond the scope of such otherwise invaluable research. For discussions on how processing stages alter the therapeutic potential of *materia medica*, see, for example, Pommerening (2006), 2017; Zhao et al., (2010); Chang et al., (2011); Wang and Franz (2014).

By using what can be gleaned from recent philological analyses of the ancient Egyptian sickness domains *seryt* and *setet* as a guide for our discussion and by choosing recipes prescribed to treat the associated experiences which a) contain reliably translatable constituents, b) show a notable level of salience or have been indicated in a previous comparative study to have therapeutic potential, and c) were found to be unique to either *seryt* or *setet*, with an additional third recipe common to both sickness categories to further problematise our discussion, we recreated three recipes according to ancient instructions. These were then subjected to NMR spectroscopy, supported by LC-MS and GC-MS analysis, to determine whether the reported effective compounds present in the *materia medica* survived the ancient processing technique. With these results, we were able to re-engage with the Egyptological discussion of the sickness domains.

1.1. *setet and seryt as both Egyptian domains of and explanatory models for sickness experience*

To frame our discussion, it is first necessary to offer a contextual summary of *setet* () and *seryt* (). These appear frequently as sickness categories in the well-published pEbers (e.g., von Deines and Westendorf, 1961-2, 773–5 and 812–14; Popko, 2021, 2024; for dating, see Kromer et al., 2019). Within pEbers are recipe lists specifically dedicated to treating the sickness experiences associated with both afflictions (Eb. 294–304, and 305–325, respectively; see e.g., Popko, 2024).

The passages dedicated to the domain-model *setet* are more explicit in both the explanatory model and domain-member aspects. The term itself represented a modular perspective: it was a bodily substance understood to be inherent in the body which needed to pour down through and flow out of the healthy body; when obstructed, it festered resulting in sick states (Russell, 2023). Associated members of this domain-model could include neck stiffness and catarrh-like symptoms, as well as a specific category of abdominal pain and two categories of elusive 'heat' in the body: *shemmet* and *dehret*. While the description of the former two are fairly explicit, the latter members are comparatively obscure. Associated abdominal pain is described as being 'like a woman who has beaten a child' – presumably likening the experience with either menstruation or even miscarriage (e.g., Grapow, 1956, 11–12). Of the heat terminology, only *dehret* is somewhat explicit, being described elsewhere in pEbers and the similarly provenanced *Edwin Smith Papyrus* as being akin to pathogenic airs—personified as demons subservient to the goddess Sekhmet—which enter into the heart and then travel throughout the body via a series of hypodermic networks (*metu*), literally 'heating the heat in his flesh' – i.e., raising the patient's temperature (see Eb. 855 h and o; cf. also Sm. vs. 1–8; Popko, 2024; Dils and Stegbauer, 2024, respectively). These pathogenic airs were associated with the period just before the yearly inundation of the River Nile, an ecological phenomenon which roughly corresponded to the modern summer season – the driest period during which the river rose and formed stagnant pools of water (Steinert and Russell, 2024), perhaps suggesting a connection with experiences related also to water-borne afflictions. *Shemmet* is even more elusive – the only indication being etymological as it was a word derived from the ancient Egyptian lexical root *shem*, meaning 'heat' (e.g., Satzinger and Stefanović, 2021).

Gaining an understanding of *seryt* is more challenging as the section of pEbers dedicated to it is less detailed and only concerns the recipe ingredients and processing instructions. The word has typically been accepted as referring to 'cough' (following Ebbell, 1924; von Deines and Westendorf, 1961; Westendorf, 1999; Popko, 2024). However, although it is clear that 'coughing' (broadly speaking) was a salient member of this domain, the coding of the text and even its writing indicate that the term primarily referred to a pathogenic substance which required removal for the restoration of health (Russell, 2024; cf. Bardinet, 1995). In particular, the expression 'removing *seryt* from the belly' frequently found as titles for these recipes implies a more dynamic modular aspect, then also suggesting a potential for greater diversity in terms of sickness experience members of the ancient domain than just 'cough', not in the least as it also implies a digestive aspect. Furthermore, any actual description of the nature of cough or expectoration—i.e., whether bloody, non-bloody, light-coloured, dark, etc.—is never explicitly noted, making it difficult to gauge the spectrum of severity encoded by the term.

2. Materials and methods

We first retranslated the passages of therapeutics from pEbers dedicated to both *seryt* and *setet*; these can be found as a supplement to the present paper (Supplement 1) and are provided together with transliterations of the original hieratic as an Egyptological standard.

2.1. Recipe translation

Recipes were retranslated and transliterated anew according to modern Egyptological standards (for grammar of Middle Egyptian, see e.g., Allen, 2013; for the most state-of-the-art dictionary and comparable text database, see TLA 2024), using open access images of pEbers from the PapyrusEbers (2024) website of the Universitätsbibliothek Leipzig. The study restricts itself to this manuscript, though future research would benefit from a comparative study of similar recipes found in other papyri, such as Papyrus Hearst (*c*. 1550 BCE), Papyrus Berlin P 3038 (*c.* 1250 BCE), and the Roman-Period Vienna Demotic Medical Papyrus (*c.* 150 CE). It should be noted that while prescribed ingredient measurements, as well as the verbs used for recipe processing instructions and other formulaic components of recipe infrastructure are translatable as they are well attested enough in other sources, sickness classifications and names for recipe ingredients are harder to elicit. The complexities involved in the former are the very topic of this paper; for the latter, one is reliant on such things as item descriptions in other texts, image-label/item-label correlations, derivatives in later stages of the language (i.e., Coptic) or cognates in other more clearly understood languages, among other means. Over-reliance on any one of these in making a positive identification is considered an assumptive methodological pitfall. The most reliably translatable items tend to be those which are more ubiquitous as they served a comparatively more important social function reflected by their frequency in the textual record. Thus, grains such as barley and emmer; various fruits like figs, dates, and carob; and substances such as oils (typically from goose or cow), honey, beers, and milk are commonly attested in the textual record (as well as in images and the archaeological record). Many other products listed in the therapeutic compendia are specific to this kind of text and therefore for these it is often almost impossible to render a reliable translation – this is particularly true of ‘herbal’ matter, i.e., ingredients marked with a -plant classifier in the script (for detailed discussions of the stated issues, see Pommerening, 2016a, 2016b).

The principal components of the recipes studied here fall into the more ubiquitous item category and as such, are translatable with relative certainty (for recipe selection, see below). The first is *it* ‘barley’ ( ) (*Hordeum vulgare* L.), which is among the most common of grain items known (von Deines and Grapow, 1959; Germer, 2008), as it was used to make the day-to-day staples of bread and beer. In the recipe reproduced, a specification for *it wadj* ‘fresh/green barley’ is found. This recipe reflects beer production (see below), and this quality of barley would be necessary for the production of malt for brewing – thus, it is taken as a euphemism to mean germinating/malted barley. The second, *djaret* ‘carob’ ( ) (*Ceratonia siliqua* L.), has been satisfactorily identified through a Coptic language derivative and its use in a comparable later Coptic therapeutic compendium (Loret, 1892; Aufrère, 1983). This item also has relative ubiquity as a ‘fruit’ in the therapeutic manuscripts, possibly as its high sugar-content would again have been useful for beer production (a notion reflected by its less common pseudonym *nedjem* ‘sweet one’ ( ), the first hieroglyph in this word physically depicting the item). The final item is *mimi* ( ), which was only very recently identified as ‘linseed’ (*Linum usitatissimum* L.) (Russell, 2024) – this is yet another item which appears in diverse source material with relative frequency. The storage and distribution of *L. usitatissimum* was a fundamental aspect of the state-governed production of flax, the fibres from which were used to weave linen for clothing (e.g., Vogelsang-Eastwood, 2000).

Linseed and barley are well represented in the archaeobotanical record and were domesticated in Egypt and West Asia during the agricultural revolution (Vartavan et al., 2010; Zohary et al., 2012).

In contrast, the archaeobotanical record of Ceratonia siliqua (carob) in ancient Egypt remains debated. While direct evidence from Egyptian sites is sparse or lacking (Thomas et al., 2024), other sources such as Vartavan et al. (2010) and the ADEMNES database (2022) suggest isolated finds. It is important to distinguish between endemic cultivation and trade-related availability: given Egypt’s well-documented import of botanical materials from the Levant, the Mediterranean, and beyond, the inclusion of non-native ingredients in medicinal recipes remains plausible, even in the absence of consistent local archaeobotanical data.

Carob appears to have been imported, and perhaps sporadically cultivated, from the southern Levant during the second millennium BCE. While the few wood samples reported from Egypt do not constitute strong evidence of widespread domestication, they suggest at least limited presence and possible use (Vartavan et al., 2010; ADEMNES, 2023).

In the text supplement, where a word cannot be translated, it is rendered in its transliteration format, but as a compound with additional information offered by the word’s classifier – e.g.: *sꜥm*-plant (with -classifier), *šnj-tꜣ*-seed/fruit (with -classifier), etc. (for a full list, see Pommerening, 2016b).

2.2. Recipe selection

Of all the recipes for *setet* and *seryt* in pEbers, only a number have fully translatable components. For *setet*, these are Eb. 206 which uses a preparation with *Hordeum vulgare* L. and Eb. 302 which uses *Ceratonia siliqua* L., specifically for the subcategory *dehret*-heat. For *seryt*, these include Eb. 305–7 and 324, all of which are similar preparations of *C. siliqua*; and Eb. 318, 322–3, which are all variants of a preparation with *Linum usitatissimum* L. Three final recipes (Eb. 309, 314–15) are more obscure in terms of content – milk and sweet products appearing to be the consistent component; the contents of these were considered too varied for a rigorous enough analysis, though such ‘cough treatments’ are well attested throughout medical history (e.g., Ebbell, 1924).

The first recipe thus selected was that which used *H. vulgare.* Eb. 206 used germinating barley grains (*it wadj*; lit.: ‘fresh/green barley’) to treat abdominal pain thought to be caused specifically by *setet.* Similarities between this recipe and the use of *Mai Ya* in modern Traditional Chinese Medicine (TCM) had been observed and discussed in a previous study (Russell et al., 2021). The comparison suggested a potential for active properties in treating abdominal pain. Thus, the selection of this recipe for analysis was considered a useful means to appraise the chosen analytical methods for examining the results of ancient Egyptian processing methods.

The second recipe which used *C. siliqua* spanned both domain-models. Not only were limited degrees of recipe variation noted in these texts, but also outside the *setet* and *seryt* recipe lists; variants of this recipe appear in other texts with the indication of removing unspecified pathogens from the belly and lung areas (Eb. 21, 35, 183, and 185). A curious feature of pEbers is that only six out over 850 therapeutic recipes listed in the 18 m-long manuscript were marked with the sign *nefer* ( ), indicating that the user of the manuscript found these recipes in particular as being ‘good’, or effective. Among those few marked with this glyph is a carob-recipe variant: Eb. 185, indicated as for ‘treating the chest (*shenbet*), removing any affliction in the belly (*chet*), and treating the lung area (*sem’a*)’ (Fig. 1). This mark further supports the notion that the Egyptians considered recipes of this kind particularly effective, observable also from the frequency that recipes of this paradigm were included in the manuscript.

The third recipe category using *L. usitatissimum* L. is curious as the physical appearance of this recipe when prepared is indicative of faecal matter coated in a slimy substance as an analogy to the modular aspect of *seryt* (i.e., a sticky matter which needs evacuation from the body via the belly; see Russell, 2024). That three variants of this recipe appear in the *seryt* recipe list is indicative of salience.

All recipes from the three ingredient groups are condensed into Table 1 (results section). This more concisely shows the recipe indications (acquired from the titles), their constituent components and quantity measurements, processing instructions, administration route,

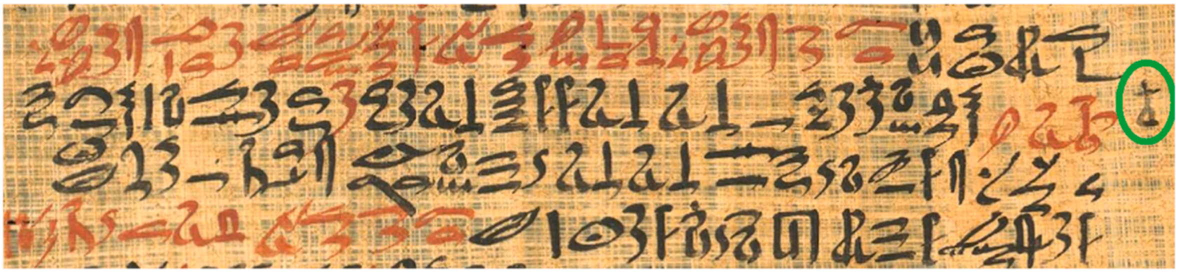

Fig. 1. The original hieratic text of Eb. 185 from pEbers; in the margin on the right-hand side can be seen the '*nefer*' marker left by an ancient scribe, here circled in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Variations of recipes in each group. Only one recipe is known from pEbers for the use of barley water; 9 recipe variants for the carob class are counted; 3 for linseed class.

Recipe type	Ebers no.	Indications of recipe	Ingredient 1	Ingredient 2	Ingredient 3	Processing step	Administration route	Duration of use
Barley	Eb. 206	Severe abdominal pain	germinating barley	water	dates	heat water gently; mix and strain with dates	oral liquid	N/A
Carob	Eb. 21	Belly evacuation	carob (300 ml)	sweet beer (600 ml)	N/A	steeped overnight	oral liquid	4 days
	Eb. 35	Belly evacuation	carob (300 ml)	watered down sweet beer (300 ml)	N/A	steeped 'until it goes bad'	oral liquid	N/A
	Eb. 183	Belly: chest, lungs, belly	carob (18.75 ml)	wine	cumin (75 ml)	heated	oral liquid	4 days
	Eb. 185	Belly: chest, lungs, belly	carob (600 ml)	watered down sweet beer (600 ml)	N/A	steeped 'until it goes bad'	oral liquid	N/A
	Eb. 302	*Setet*: treating *dehret*-fever	carob	beer	honey	ground	oral liquid	N/A
	Eb. 305	*Sereyt*	fresh carob	water	N/A	steeped	oral liquid	4 days
	Eb. 306	*Sereyt*	carob	sweet beer	N/A	steeped	oral liquid	4 days
	Eb. 307	*Sereyt*	carob (half *rmn.t* measure?)	water (half *rmn.t* measure?)	N/A	steeped for four days	oral liquid	4 days
	Eb. 324	*Sereyt*; belly	fresh carob (half *rmn.t* measure?)	water (half *rmn.t* measure?)	N/A	steeped	oral liquid	4 days
Linseed	Eb. 318	*Sereyt*	linseed flour (300 ml)	goose-oil (300 ml)	honey (300 ml)	heated	oral solid	4 days
	Eb. 322	*Sereyt*; belly	parched linseed	beer	N/A	warmed in bread mold; made into a biscuit	oral solid	2 days
	Eb. 323	*Sereyt*; belly	parched linseed (580 ml)	cow-fat (580 ml)	honey (580 ml)	1160 ml yeast-liquid with gum arabic (unspecified) ground finely; heated	oral solid	N/A

and duration of use (where stated).

2.3. Recipe recreation

The L. *usitatissimum*, *C. siliqua*, and *H. vulgare* used were purchased in the local market (Rotterdam, The Netherlands), and not from Egypt itself. The reasons for doing so are twofold: first, from the historical perspective, one cannot assume that a product grown in Egypt today would be more identical than anything available elsewhere to that grown over 3500 years in the past. Especially since the Aswan damn projects in the 1960s which—despite the plethora of benefits including land-reclamation, multi-cropping and overall increased agricultural yields, and protections against drought—those agricultural areas are more frequently waterlogged with increased salinisation caused by the lack of the annual flood especially in the Nile Delta (e.g., Abd-el Monsef et al., 2015). In fact, the notable difference in water-table between the ancient and modern worlds is most observable on ancient monuments in low-lying areas since the dams' construction, where the rate with which the porosity of the ancient limestone 'wicks' water and damaging salts upwards has increased significantly, impacting their overall integrity (e.g., Smith, 1986). Secondly, as the investigation was among the first of its kind applied in historical research, the central objective remained to test for indicators that would suggest bioactive profiles would have the potential for being present in the ancient concoctions, not to measure their presence in the modern version as an absolute reflection of the former. Despite the differences between the ancient and modern Egyptian environments, it remains recommended to use materials sourced from the region in question in any further research in this direction, as climate and environment can have an effect on metabolite development (e.g., Pommerening, 2006; Borim de Souza et al., 2023). The herbal materials were identified by Professor Tinde van Adel of Wageningen and Leiden Universities. Voucher specimens are stored at Fytagoras (FG-eg2021A1 (*Linum usitatissimum* L.) FG-eg-2021-A2 (fruit pods *Ceratonia siliqua* L.) and FG-eg-2021-A3 (grains *Hordeum vulgare* L.).

Another issue to address in recreating these recipes was the vagueness of the ancient term used as a processing instruction: *pesi* 'to heat'. The recipe instructions specify the need for them to be 'heated', but to what degree and for how long was never explicitly stated. The verb itself appears somewhat neutral (compare the verb *senwekh* 'to incinerate', a less common but more extreme heating instruction; e.g., Pommerening, 2017). Of the recipes analysed in the present study, only Ebers 206 contains more specific instructions regarding the heat, stating the concoction is to be 'heated (*pesi*) without letting it (the combined matter) boil'. An estimation was required to interpret this unusually specific instruction; we opt here for a sustained heat of 60 °C – and so pre-boiling. While it should be noted that the peculiarity of this elaboration likely applied only to this particular recipe, it provides a useful starting point for which to address the silence of the others and standardise heat applied in our investigation. Any indication of duration was impossible to elicit; we chose a period of 4 h, informed by typical heating periods used in Traditional Chinese Medicine (TCM) (e.g., Zhang et al., 2014).

Eb. 206 was a therapeutic drink produced from germinating barley seeds steeped in water and heated together without boiling; this mixture was then taken and mixed with date fruits. Unlike the second and third recreations, Eb. 206 provides no exact measurements for this recipe's constituents; however, the ingredients used appear to mimic those used in the production of beer. In the production of ancient Egyptian beers, both barley and emmer (*Triticum dicoccon* (Schrank) Schübl.) were the core constituents, though the former in relatively smaller quantities (see Samuel, 2000; also Helck, 1971). Date fruits (*Phoenix dactylifera* L.) are the only so-far reported assumed inclusion used to increase the sugar content of brews (cf. above discussion of *C. siliqua*), their skins also contain a high-yield of yeast-culture (Faltings, 1991; cf. Samuel, 2000), though in theory, other available high-yeast yielding ingredients, such as grapes (*Vitis vinifera* L.), would have the same effect. Although the recipe taps into the ancient Egyptian brewing technology, the text makes clear that barley was considered the singular principal dry-ingredient and water the principal liquid vehicle. We therefore estimated a 1:1 ratio of barley and water, each at a volume 300 ml, equalling 1-'*dja*-unit', the system by which ingredients are measured elsewhere in the ancient manuscript (see Pommerening, 2003). The mixture was heated to 60 °C, thereby not boiling it; unlike the other two recipes, the recipe was decidedly heated only for 2 h, reflecting an expected higher-end duration of a typical brewing process. After the solution cooled, the date fruits were added as prescribed.

The second recipe paradigm investigated consisted of a drink decoction made from carob pods (*Ceratonia siliqua* L.) processed in equal volumes with either water or beer, the latter being a light-alcoholic fluid between the ranges of 4–6 % ABV (Samuel and Bolt, 1995; Samuel, 2000) (cf. e.g., Eb. 305–7; see Table 1). Three variations of the recipe class were prepared for analysis, for which we used 100 ml of chopped carob, and 100 ml of the chosen liquid. The first two preparations used ethanol-solutions as a replacement for the ancient beer, as the inclusions of other matter in beer can obscure the results of the metabolic profile analysis. Given the potential variability in alcohol content of ancient Egyptian beer, the first preparation used an ethanol solution at 5 % ABV, and the second at 10 %. The third preparation instead combined chopped carob with water. Following the recipe instructions, these concoctions were left to steep for 24 h (overnight, as instructed by the Egyptian recipes), and then observed and subjected to the analyses.

The third paradigm investigated were those that used linseed; though the paradigm showed a variant in which linseed was processed with beer (Eb. 322), that which used honey and oil was chosen (Eb. 318), as a similar variant appears in the same list (Eb. 323). Rather than a drink, all variants produce a sticky-solid therapeutic, not unlike a biscuit (in the British-English sense of the word) which was intended to be eaten (Russell, 2024). Eb. 318 and its close variant Eb. 323 use a 1:1 ratio of the three principal components (1-*dja* or 1-*hin* each in Egyptian measurements ≈ 300 ml and 480 ml, respectively). The 300 ml (1-*dja*) of each item specified in the linseed-fat-honey recipes was reduced to 7.5 ml of each for manageability (3.28 g of linseed); for the linseed-beer recipe, 100 ml (46.90 g of linseed) was used instead. Eb. 318 specifies the use of 'linseed flour'; the other two do not. For consistency, we opted for milled linseed. For Eb. 322, two recipe samples were created: one with 5 % ethanol solution, the second with 10 % ethanol solution. All were again incubated at 60 °C for 4 h. The samples prepared with either 5 % or 10 % ethanol solutions produced very similar results. Thus, we present only tables from the 5 % ethanol range for discussion.

2.4. Metabolites profiling

We subjected the concoctions to nuclear magnetic resonance (^{1}H-NMR) spectroscopy which is a robust method to obtain a holistic view of the constituents in a herbal extract as well as an indication of their quantities. NMR spectroscopy provides a broad overview of metabolite profiling, as it has the ability to detect a wide range of metabolites. However, due to its limited sensitivity, it is often complemented by more sensitive analytical techniques such as liquid Chromatography-mass spectrometry (LC-MS) or gas chromatography-mass spectrometry (GC-MS). In our research, we employed GC-MS and LC-MS separately as complementary methods to enhance metabolite detection. These techniques allowed for the identification of minor compounds that might have been overlooked by NMR alone, thereby providing a more comprehensive metabolic profile.

For NMR analysis, 10 mg of freeze-dried extracts were weighed and dissolved in the mixture of MeOD and phosphate buffer in D_2O (1:1 v/v), pH 6.0 containing internal standard (3-(trimethylsilyl) propionic-2,2,3,3-d_4 acid sodium salt, TSP). Samples were vortexed and ultrasonicated to dissolve completely. After centrifugation for 10 min at room temperature, 300 μl of supernatant was transferred to a 3.0 mm NMR tube. NMR analysis was followed the protocol described in Wei et al. (2021). For the identification of the metabolites an in-house database was used. For LC-MS and GC-MS analyses, see details in the supplementary document (Supplement 2).

The list of the identified metabolites was used for screening the scientific literature for putative medicinal activity and the relationship to possible sickness experiences identified through the philological analysis as potential members of the *seryt* and *setet* domain-models. This is discussed in more detail below for each selected herbal preparation individual.

3. Results

An overview of the comparable components of the three recipe categories are observable in Table 1. The recipe using germinated barley grains treating abdominal pains associated with *setet* is the only recipe of its kind. For the recipes that use carob and linseed, however, the Ebers Papyrus includes variant examples where certain components are more variable (e.g., volume measurement and vehicles) and others which are principal core features of a recipe of that paradigm. These are recipes which create an edible linseed matter or a drinkable carob infusion respectively. Eb. 206, 306, and 318 are therefore here viewed as the simplest form of each, and it is these which were recreated and their results from their analyses which are discussed here.

3.1. Hordeum vulgare

Eb. 206 was used for treating severe abdominal pain, possibly related to digestive problems. In the present Egyptological literature, *H. vulgare* is interpreted 'not as a therapeutic in the proper sense, but really as a base for other substances' (translated from German; Germer, 2008, 38). Barley contains a lot of dietary fibres and the beneficial effects of these in gastrointestinal health are extensively described in the scientific literature and recently reviewed, including for example the use of these fibres in relieving pain as a symptom of irritable bowel syndrome (Gill et al., 2021). Germinating barley grains are known to contain maltose and dextrin derived from the degradation of starch in the endosperm of the grain during its germination (Andriotis et al., 2016). These are reported to mildly promote secretion of gastric acid and pepsin in the stomach, having a noticeable effect on treating abdominal cramps and diarrhoea (Marieb and Hoehn, 2015). In TCM in the preparation of germinating barley seeds known as *Mai Ya* is listed with this indication in the Pharmacopiea of People's Republic of China (PPRC, 2020; Zhen, 2013;

Russell et al., 2021).

The [1]H-NMR profile suggested the presence of a high number of phenolic compounds that have very typical signals of *p*-substituted benzene, tyrosine-like structures (Fig. 2). Experimental and *in-silico* HPLC-ESI-qToF-MS/MS data analyses suggest that the most abundant compound of these phenolics might be hordenine, the main modified biogenic amine reported from barley (Supplement 2, Fig. S1 and S2) (Wang et al., 2022).

Hordenine is allelopathic and occurs in high quantities in germinating barley grains (Smith, 1977; Liu and Lovett, 1993; Lovett et al., 1994). Pharmacologically, hordenine is an indirect sympathomimetic compound that promotes the release of noradrenaline, thereby enhancing adrenergic signalling and it was recently described as potent and selective agonist of the dopamine D2 receptor, understood as the best agonist out of 17,000 tested food ingredients (Sommer et al., 2017). It can supposedly cross the blood-brain-barrier, especially in the presence of MAO-B inhibitors as reported for other bioactive modified biogenic amines such as *N,N*-dimethyltryptamine (McKenna et al., 1984; Berlowitz et al., 2022; Morales-Garcia et al., 2020; van Oorsouw et al., 2022). Besides the brain, D2-receptors are widely present in the gastrointestinal (GI) tract (al-Jahmany et al., 2004). Dopamine is an important modulator of GI exocrine secretory and is fluid absorptive; it was demonstrated that agonists of the dopamine D2 receptor, like hordenine, were able to stimulate the gastrin secretion in rats (Eliassi et al., 2008). It may also relieve abdominal pain by increasing gastrointestinal motility and improving blood flow to the digestive tract, as well as having anti-inflammatory and analgesic effects (Xu et al., 2023). The ancient Egyptians added dates (*Phoenix dactylifera* L.) to Eb. 206. Dates are rich in bioactive compounds such as flavonoids, including quercetin, apigenin and kaempferol, and phenolic acids such as ferulic acid and *p*-coumaric acid. Thus, in addition to hordenine, ferulic acid and *p*-coumaric acid derivatives were detected by NMR (minor signals in the aromatic area) and confirmed by LC-MS (Supplement 2, Fig. S3 and S4). These substances are known for their antioxidant and neuroprotective properties, especially the flavonoids quercetin, apigenin and kaempferol having a mild inhibitory effect on MAO A and B (Bandaruk et al., 2012; Sivaraman et al., 2015; Olayinka et al., 2023). This addition could potentiate the pharmacological effect of sprouted barley hordenine by inhibiting degradation by monoamine oxidase (MAO) enzymes, thus prolonging the sympathomimetic effect, and even potentially allowing for central D2 receptor mediated effects (McKenna et al., 1984; van Oorsouw et al., 2022).

3.1.1. *Ceratonia siliqua*

According to recipes observed in pEbers, drinks made with carob fruit (*Ceratonia siliqua* L.) were used to ‘remove’ *seryt* from the ‘belly’, the ‘chest’ and ‘lungs’ – the former perhaps indicating a digestive complaint-aspect as a primary experience of sickness; the latter instead indicating bronchial afflictions. It also treated *dehret*-heat that is listed in the manuscript as a member of the *setet* cultural domain – this member was notably associated with seasonal fevers caused during the time of the inundation. The laxative activity of carob pods has been reported (Rtibi et al., 2016, 2017), but no information is available on the health-related effects of carob in relation to cough or irritation of the bronchia. In the [1]H-NMR spectrum of the 5 % ethanolic sample preparation of carob, the secondary metabolites gallate and epicatechin-gallate could be detected in the aromatic area as well as phenylalanine, tyrosine and formate (Fig. 3).

Gallate and epicatechin-gallate are related to the treatment of pulmonary irritation and cough. The Indian traditional Ayurvedic formulation Kanakasava contains high amounts of gallate and the anti-asthmatic potential of Kanakasava was demonstrated in ovalbumin-induced bronchial asthma and airway inflammation in rats (Arora et al., 2017). Moreover, it was demonstrated that Epigallocatechin-3-gallate reduces allergen-induced asthma-like reaction in sensitized guinea pigs (Bani et al., 2006). It has also been shown that severe fever due to viral infection could be inhibited by catechins from green tea (Ogawa et al., 2021).

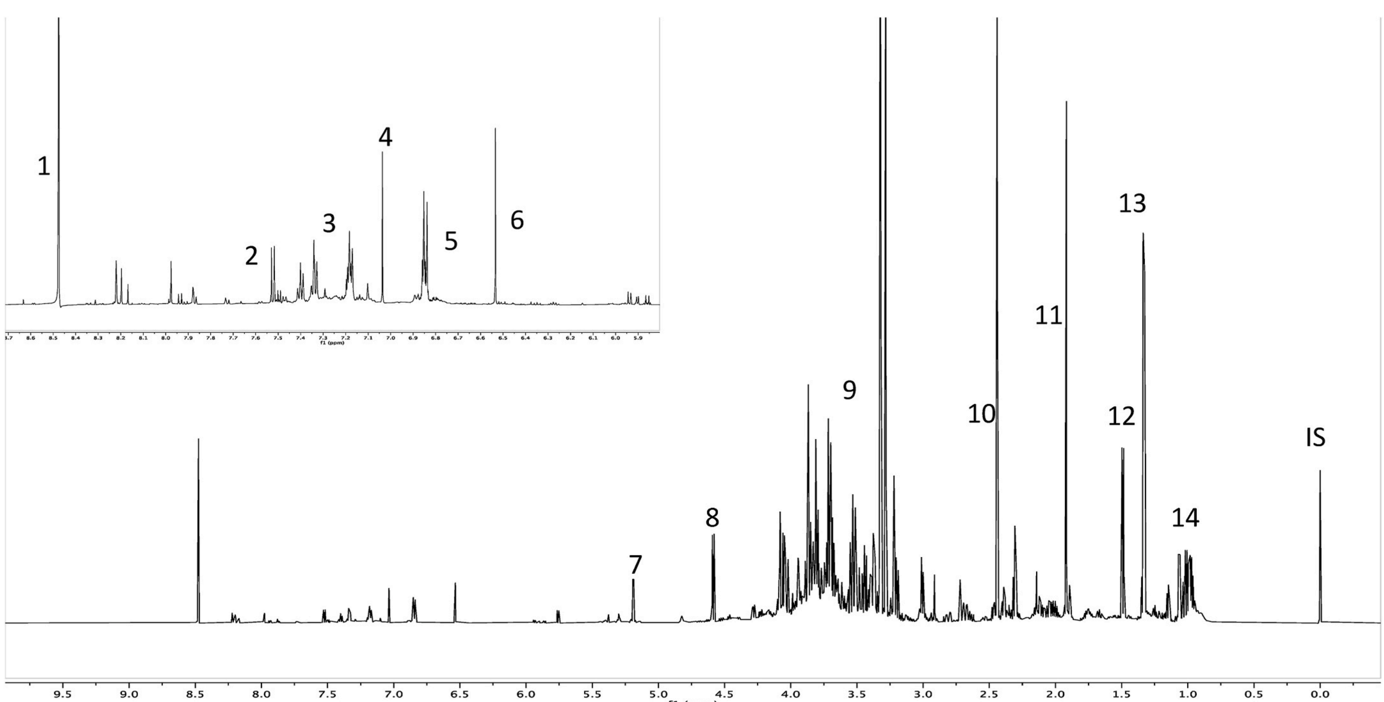

Fig. 2. [1]H-NMR of Barley extract. Barley was extracted with hot water (60°C for 2 h) and measured in MeOD-D_2O phosphate buffer at pH 6 as described in the method section 2.4.
All range (d 10.00–0.00) was shown and the aromatic area (d 8.7–5.8) was expanded in the insert figure. Numbers indicate the signals from following metabolites. 1: formate, 2, 5: tyrosine, 3: hordenine, 4: gallate, 6: fumarate, 7: sucrose (b-glucose moiety), 8: sucrose (a-glucose moiety), 9: sugars, 10: succinate, 11: acetate, 12: alanine, 13: threonine, 14: amino acids (valine, leucine, isoleucine), IS: Internal standard (TSP).

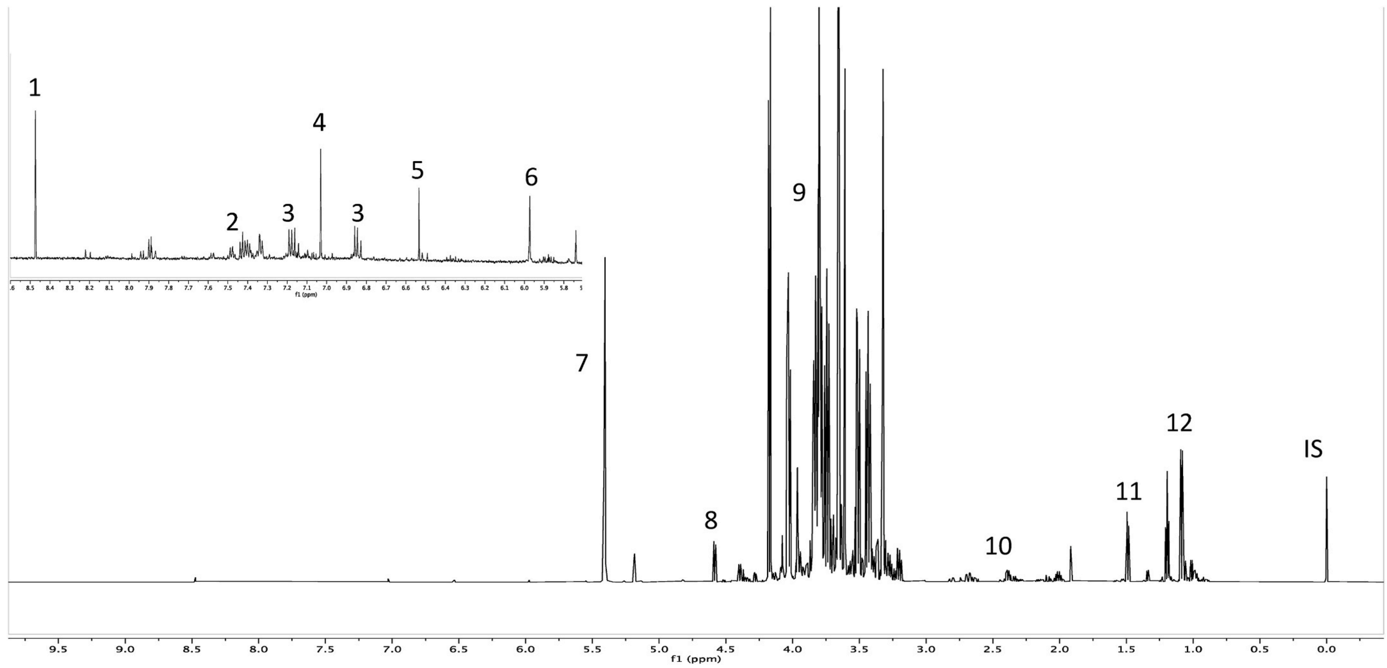

Fig. 3. [1]H-NMR of carob extract. Carob was extracted with 5 % EtOH and measured in MeOD-D_2O phosphate buffer at pH 6 as described in the method section. All range (d 10.00–0.00) was shown and the aromatic area (d 8.7–5.8) was expanded in the insert figure. Numbers indicate the signals from following metabolites. 1: formate, 2: phenylalnine, 3: tyrosine, 4: gallate, 5: fumarate, 6: epi-catechin gallate, 7: sucrose (b-glucose moiety), 8: sucrose (a-glucose moiety), 9: sugars, 10: glutamate, 11: alanine, 12: threonine, IS: Internal standard (TSP).

Incidentally, this class of molecules has a putative anti-malaria activity – it is able to bind to adhesion molecules, preventing the grip of *Plasmodium falciparum*-infected erythrocytes to the endothelium of blood vessels. Additionally, they inhibit the gliding motility of sporozoites, preventing invasion and interrupting the parasite's cycle (Hellmann et al., 2010). It is worth noting that, although also incidental, for polyphenolic compounds like epicatechin-gallate, anti-tuberculosis activity was demonstrated after fractionation of the polyphenolic

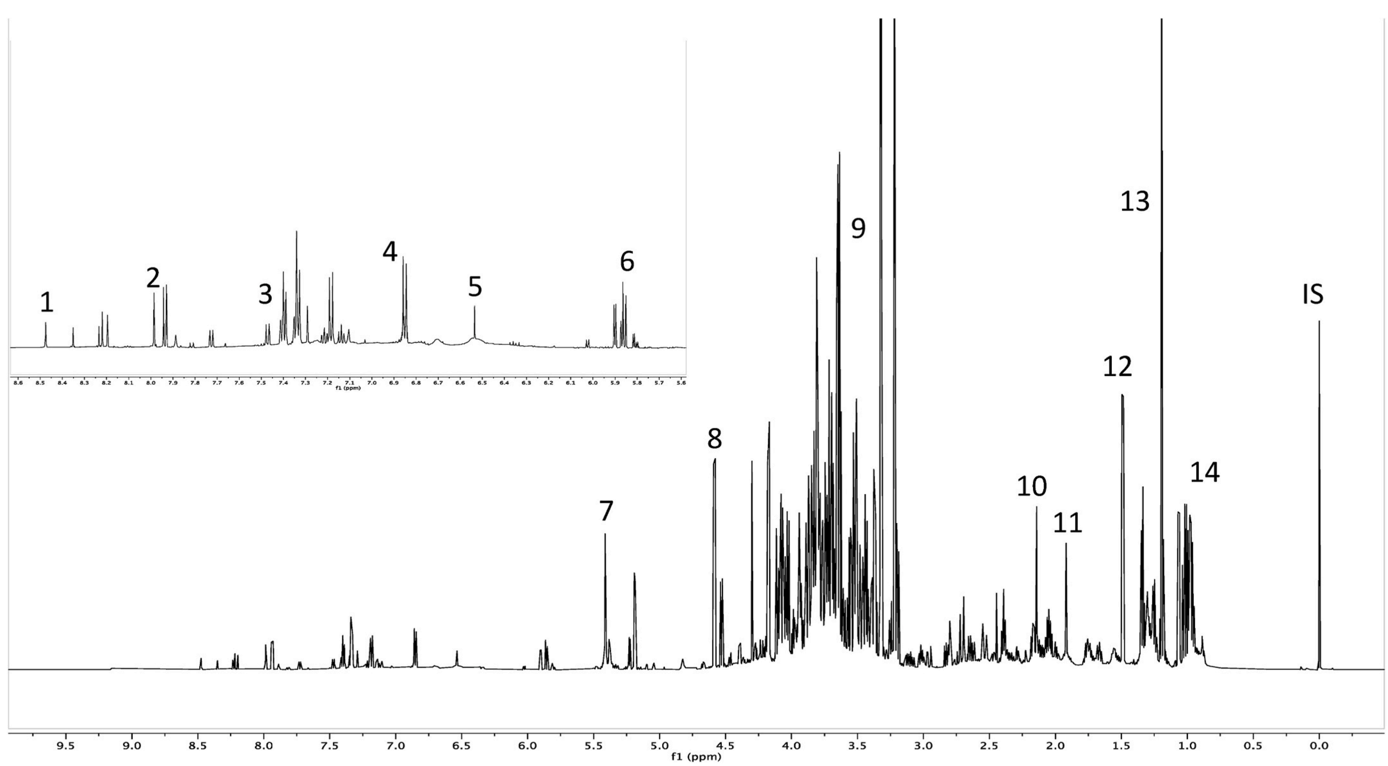

Fig. 4. [1]H-NMR of linseed extract. Linseed was extracted with 5 % EtOH and measured MeOD-D_2O phosphate buffer at pH 6 as described in the method section. All range (d 10.00–0.00) was shown and the aromatic area (d 8.7–5.8) was expanded in the insert figure. Numbers indicate the signals from following metabolites. 1: formate, 2: guanosine, 3: tryptophan, 4: tyrosine, 5: gallate, 6: lignan, 7: sucrose (b-glucose moiety), 8: sucrose (a-glucose moiety), 9: sugars, 10: succinate, 11: acetate, 12: alanine, 13: threonine, 14: amino acids (valine, leucine, isoleucine), IS: Internal standard (TSP).

content of the areca-nut *Areca catechu* (Raju et al., 2021; Anand et al., 2006).

3.2. *Linum usitatissimum*

The bulk-laxative effect of linseed is well-known, and is referred to in historical sources such as Dioscorides (Benedum et al., 2006). In addition to this, its pain-relieving effects and use as an expectorant have been noted (Benedum et al., 2006; HMPC, 2015), and the antitussive effects (reducing cough) of ethanolic extracts of linseed have already been reported (Saadat et al., 2018). Together with the available literature, the proposed health-related activities of linseed (*Linum usitatissimum* L) as translated from pEbers (Eb. 318; 322–3) suggest that it was used to reduce symptoms of cough, bronchitis, and has anti-inflammatory effects, seemingly by the reduction of pain during swelling. From the NMR analysis, major primary metabolites could be detected such as sugars (glucose) and amino acids (phenylalanine, tryptophan, glutamate, glutamine, threonine, valine, alanine and leucine). In the aromatic area of the NMR spectrum the possible signals of the health-related secondary metabolite class of lignans could be detected (Fig. 4).

Lignans show health beneficial activities in relation to cough and bronchitis. Lignans in plant extracts of *Schisandra chinensis* are likely involved in reducing cough effects in cough hypersensitive guinea pig models (Zhong et al., 2021). Further identification of health-related secondary metabolites could be achieved by LC-MS and GC-MS (Supplement 2, Fig. S5). From these analytical techniques, stilbenoid (LC-MS) and tocopherol (GC-MS) could be detected. For both compounds there is no direct evidence reported in the literature that these are beneficial for treating cough and/or bronchitis. However, the orchid *Arundina graminifolia* has been used for treating bronchitis in traditional Chinese medicine, and stilbenoids are described as one of the major active substances in this prescription (Zhang et al., 2021). In general stilbenes are compounds with reported activities against a broad range of indications including anti-inflammation (Zhou et al., 2024). Therefore, the beneficial effects of stilbenoids, tocopherol, and lignans for treating cough and bronchitis may be attributed to their anti-inflammatory and possible immunomodulation effects. The anti-inflammatory effects of linseed have already been described by Rafieian-Kopaei et al. (2017) and Kaithwas et al. (2011). The anti-inflammatory activity of stilbenoids has been reviewed by Dvorakova and Landa (2017) and lignans in linseed have been recently reviewed by Shayan et al. (2020). In addition, tocopherols are very strong antioxidants. In general, strong antioxidants expose anti-inflammatory effects by inhibiting the production of ROS (Reactive Oxygen Species) (Yahfoufi et al., 2018). More specifically tocopherols are known to inhibit inflammatory responses via T-cells and affecting inflammatory mediators (Lewis et al., 2019).

4. Discussion

As outlined at the start of this paper (section 1.1.), both *setet* and *seryt* can be considered domain-models – that is, they were considered tangible substances found within the body which were pathogenic and used to explain a wider domains of sickness experiences. Within the larger domain-model of *setet*, traditional philological analyses observe severe abdominal pains being considered as one potential experience member, and a category of 'heat'—perhaps related to fever—that was considered related to the seasonal inundation of the Nile. A treatment for this latter was also found as a salient type of therapeutic for treating sickness experiences categorised under the *seryt* domain-model. Experiences for this category are less explicit in the texts, but certainly 'coughing' (presumably of all varieties)—or perhaps even less specifically, bronchial afflictions—is clearly deducible as a member through traditional philological routes. Where the blurred boundaries between these domains was to be found, is unclear through philological routes alone, but could be indicated by the profiling of recipes singular to either domain, or common to both.

The activities present in the concoction using germinating grains of *H. vulgare* to treat severe abdominal pain—categorised as a member of the *setet*-domain-model—indicates that empirical pharmacological observation played a role in both the selection of principal components for the therapy, as well as the chosen preparation methods. Indeed, the profiling demonstrated that the ancient decision to specifically use germinating barley grains, to process them with heated but not boiled water and to combine with date fruits is an example where the synergism in combining the items exceeds the known dietary fibres present in the seed alone. The presence of hordenine in the reproduced therapeutic is indicative indeed of observations that such a preparation was beneficial to the promotion of digestion and treating pain in the digestive tract, which appears to be further potentiated by the addition of and exposure to date fruits. The combination of hordenine-producing germinating barley with MAO-inhibiting compounds (such as quercetin, apigenin, and kaempferol) from dates may have been designed, whether deliberately or empirically, to enhance and prolong the bioactivity of its constituents. This reflects a potential understanding of pharmacological synergy, whereby the therapeutic effect of one plant is enhanced by another through metabolic modulation. Such strategies are well documented in various traditional medical systems. While cultural and historical contexts differ widely, similar pharmacodynamic pairings, such as combining monoamine receptor agonists with MAO inhibitors, are known from other ethnomedical practices. For example, indigenous cultures in the Amazon and Orinoco basins have long used combinations of psychoactive plants in ceremonial and healing contexts, where one plant enhances the bioavailability and central action of another (McKenna, 2004; Palhano-Fontes et al., 2014). We include this parallel not to imply a direct cultural link, but to illustrate how similar pharmacological principles may arise independently through empirical observation and practice. Through philological analyses, so far, no parallel recipe of this kind has been identified as being considered appropriate to treat sickness experiences considered members of *seryt*. In this case, this unique correlation between experience description and profiling of prescribed therapeutic is unique to the *setet* domain-model.

Similarly unique was the application of *L. usitatissimum* seed for the treatment of the *seryt* domain-model. Unlike the aforementioned recipe text, the precise sickness experience is not described in the available text for this usage. In this regard, the chemical profiling of the therapeutic can at least support the conclusion from philological analyses that the term *seryt* represented a domain-model, for which bronchial afflictions (broadly speaking but including cough) appears as a chief experience member. The known bulk-laxative effect of linseed retained by the processing method appears to correlate with the modular aspect of *seryt* as a sickness causing substance that needs removal from the belly for the resumption of health. Nonetheless, in terms of sickness experience members of the domain aspect, the possible signals of lignans detected in the aromatic area of the NMR spectrum could be suggestive of the processed matter's benefits in reducing symptoms related to cough and bronchitis, and this is also qualified by the potential secondary metabolites indicated through supplementary LC-MS and GC-MS. Its pain-relieving, antitussive, and expectorant capabilities as they are reported in today's literature may have contributed to the motivation to include the ingredient in *seryt*-recipes, and minor signals of lignans and stilbenoids detected are of interest, but without further analysis, the results are certainly less conclusive. Unlike the recipe for *H. vulgare*, it remains to be questioned whether this processing method would be the most effective method available to the Egyptians for producing comparable results. In any case, these provisional hints—that both modular and domain aspects of *seryt* are in focus in this recipe, together with the knowledge that its use was specific to this domain-model according to the philological analyses—certainly invoke further research in this direction.

As with the recipe using *L. usitatissimum*, the precise indication for the final recipe explored here which used *C. siliqua* as its principal component is unavailable from the text. Nonetheless, unlike the former therapeutic, this one was administered to 'remove *dehret*-heat', an experience which appears likely related to seasonal fevers from philological analyses, a specific domain-member of the *setet* domain-model, as well as to treat experiences belonging to *seryt*. In both cases, both *dehret* and *seryt* are to be removed from the belly. As with L. *usitatissimum*, this modular aspect of the therapeutic, to be removed from the belly, might correlate well with observations of reported laxative activities for carob. The NMR spectrum of the therapeutic processed according to the ancient Egyptian recipe indicates a presence of gallate and epicatechin-gallate, both of which are related to the treatment of bronchial conditions in the scientific literature. The degree of their presence appears minimal, though as there is presently no scientific literature on health-related effects of carob in relation to cough or irritation of the bronchia, these detections should perhaps not be disregarded as a philological aid. Additionally, the putative anti-malarial activity of this class of molecules might be relevant for a connection between therapeutic and the seasonal *dehret*-heat/fever associated with the Nile's inundation, categorised under *setet* in pEbers. Without more detailed data from further analyses, however, emphasis on these results in philological analyses should be minimal. Nevertheless, through such further analyses, further investigations of recipes such as this common to both domain-models might add additional insight into the blurred boundaries between the domains.

5. Conclusions

Our study demonstrates two key conclusions, and a number of other insights which can aid future interpretations of ancient Egyptian therapeutics more broadly. Chief among all is the observation that in all three cases, known activities of all three principal recipe components—*H. vulgare*, *L. usitatissimum*, and *C. siliqua*—were not diminished by the ancient processing instructions. Rather, in the case of the latter two, signals from the NMR and provisional GC-MS and LC-MS approaches hinted towards activities that corresponded to the sickness experiences associated with both the *setet* and *seryt* domain-models, as well as with the modular aspect that both constituted substances that required removal from the belly for the restoration of health (i.e., laxative properties). The case of *H. vulgare* was more interesting still, as the profiling of this recipe demonstrated that the ancient Egyptian processing method actually maximized the synergistic effects produced through inclusion of other items.

Our study thus demonstrates the usefulness of profiling for more detailed ancient ethnopharmacological inquiries, where bioactive properties of concoctions are suspected as a primary motivation for their use (see e.g., Pommerening, 2005; Kusch et al., 2011; Kadioglu et al., 2016). When applied with caution, the profiling tool can further complicate and refine the questions often asked in philological inquiry, especially concerning the significance of processing activities in the minds of members of ancient societies, beyond the 'magical' and 'ritual'. This alone demonstrates that profile analyses as an additional research tool shows promise even at this preliminary stage. It is important to emphasize that while some ingredients identified in ancient recipes remain in therapeutic use today, their safety and efficacy depend on plant-cultivation parameters (e.g. location, soil, harvest date and time), preparation methods, and individual health context. Further refinement of approaches—such as using products sourced from Egypt despite the obvious differences in ancient and modern soil constitution, and by conducting secondary and even tertiary analyses on produced recipe samples, integrated with AI-assisted NMR- and MS-based metabolomics workflows (Reher et al., 2020; Dührkop et al., 2020)—are recommended for future incentives.

Another direction for future research would be to establish parameters of recipe paradigms. Other therapeutic papyri exist from Egypt, such as the aforementioned pHearst, pBerlin P 3038, and pDemotic Vienna Medical Papyrus. Furthermore, contemporaneous sources also exist from Mesopotamia, and it would be useful to study trends in recipe classes within these cuneiform tablets to determine whether identified recipe paradigms were pervasive in ancient Egyptian texts alone, or more broadly in ancient Western Asia.

The method used here can be expanded to other recipes from such sources, providing more data that might shed further light on the layered motivations behind ancient recipe construction, as well as the members of ancient domains. The latter can aid in moving us further away from any attempt to map modern categories of sickness on ancient labels, such as 'malaria/fever' on *dehret* or even 'cough' on *seryt*. In addition to the diversity of potential experiences suggested for these categories by this limited study, the importance of the explanatory model behind each sickness classification might be better understood through profiling as a philological tool.

CRediT authorship contribution statement

Jonny Russell: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hye Kyong Kim:** Writing – review & editing, Visualization, Validation, Software, Resources, Formal analysis, Data curation, Conceptualization. **Henrie Korthout:** Writing – review & editing, Resources, Project administration, Investigation, Formal analysis, Data curation, Conceptualization. **Amira Naimi:** Writing – review & editing, Visualization, Formal analysis, Data curation. **Raphael Reher:** Writing – review & editing, Supervision, Methodology, Formal analysis, Data curation. **Bert van Duijn:** Project administration, Methodology, Conceptualization. **Mei Wang:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization. **Tanja Pommerening:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jep.2025.120498.

List of Abbreviations

ABV Alcohol by volume
ADEMNES Archaeobotanical Database of Eastern Mediterranean and Near Eastern Sites (https://www.ademnes.de/)
BCE before the common era
D_2O Deuterated water
Eb Ebers papyrus text number
HPLC-ESI-qToF-MS/MS High-performance liquid chromatography with electrospray ionization coupled to a quadrupole time-of-flight mass spectrometer mass spectrometry
GC-MS gas chromatography-mass spectrometry

LC-MS liquid chromatography-mass spectrometry
MAO-A: Monoamine Oxidase A
MAO-B: Monoamine Oxidase B
MeOD Deuterated Methanol
NMR nuclear magnetic resonance spectroscopy
pEbers The Ebers Papyrus (https://papyrusebers.de/)
TCM Traditional Chinese Medicine
TLA Thesaurus Linguae Aegyptiae (https://thesaurus-linguae-aegyptiae.de/search)
TSP 3-(trimethylsilyl) propionic-2,2,3,3-d_4 acid sodium salt

Data availability

Data will be made available on request.

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