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RESEARCH ARTICLE

Flax for seed or fibre use? Flax capsules from ancient Egyptian sites (3rd millennium BC to second century AD) compared with modern flax genebank accessions

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Abstract In order to determine whether ancient Egyptians had already selected and cultivated very specialized flax types according to their purpose for textile or oil production, respectively, we compared archaeobotanical flax finds with nearly 3000 diverse genebank accessions kept at the Plant Gene Resources of Canada (PGRC). The main result was that fibre flax was most probably already cultivated during the 3rd millennium BC, whereas in later periods an intermediate flax and/or oil type was in use. The collaboration between archaeobotanists and genebank curators shows how our knowledge about ancient usage of plants can be improved by interpreting observations made on ancient findings using recent characterization data obtained from diverse genebank material.

Keywords Archaeobotany · Genebank collections · Domestication · Ancient Egypt · *Linum usitatissimum*

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Introduction

Plant finds from archaeological sites can, in most cases, be determined to the species level but rarely to the level of infraspecific groups with specific features. Flax (*Linum usitatissimum* L.) is one of the founder crops for agriculture in the Near East (Weiss and Zohary 2011). Flax comprises two main usage groups with distinct phenotypes: fibre flax types that produce a long, unbranched stem, and oil flax (linseed) types that produce more and larger seeds for direct consumption or oil extraction (Körber-Grohne 1987). Additionally, some flax types display an intermediate phenotype between these two extremes and may have been used for both purposes (Kulpa and Danert 1962). Taxonomists have described the diversity in flax and distinguished infraspecific groups based on research of world collections of flax in genebanks, reflecting these distinct usage groups based on seed and capsule features, among others (Helbaek 1959; Kupla and Danert 1962).

The main objective of this study is to discuss whether the archaeological flax capsules from Ancient Egypt already represent a specialised production for oil or fibre, or the intermediate type usable for both purposes. The flax capsules being examined span a wide chronological period (3000 BC-100 AD) and are part of the collection at the Botanical Museum of the Free University of Berlin. To establish a comprehensive and reliable basis for comparing capsule dimensions in archaeological findings, the

measurements of the ancient samples were compared with a diverse range of flax germplasm preserved by Plant Gene Resources of Canada, located in Saskatoon, Province Saskatchewan.

State of the art and objective of the study

Archaeological findings of cultivated plants are important for understanding their evolution (Helbæk 1959). The domestication and evolution of flax, its spread from its original geographical locations of domestication, and its diverse uses still present many unanswered questions (Karg 2020). Determining the precise origins of different types of flax (fibre flax and linseed) and their primary uses in various regions continues to be a challenging task.

Flax seeds are rich in polyunsaturated fatty acids, specifically linoleic acid omega-6 (ω-6) and α-linolenic acid omega-3 (ω-3). These fatty acids are essential nutrients for humans and must be obtained through ingestion, as our bodies cannot produce them. The oil can be extracted from crushed flax seeds by boiling them in water. Once the liquid has cooled and the solid plant tissues have been removed, the oil can be separated. This extraction process has been archaeologically documented through the discovery of flax seeds in vessels dating back to the Iron Age, such as those found at the Tel Beth-Shean site in Israel, as discussed by Kislev et al. (2011) and Cassuto et al. (2022). Textiles made from flax fibres have also been found in ancient cave deposits in Nahal Hemar, Israel, dating back to the 7th millennium BC (Shamir and Rast Eicher 2020), leaving the debate open as to whether flax was first cultivated for its seed oil or fibre use. Identifying the type of flax being studied provides insight into the agricultural and economic context of archaeological findings.

Currently, biometric research of ancient flax seeds appears to be a suitable method for distinguishing different types of flax (Herbig and Maier 2011; Karg et al. 2018). In Central Europe, there was a clear change in seed size during the 4th/3rd millennium BC, with smaller seeds replacing the larger ones found in earlier deposits. The larger-seeded flax in that region is believed to have been used for its oil, while the smaller-seeded flax was used for textile production. This is supported by a contemporaneous increase in textiles made from flax fibres and the presence of numerous textile tools in the archaeological record of this region (Rast-Eicher and Dietrich 2015; Karg 2022).

Renowned for its linen production, Ancient Egypt had a rich history of cultivating, utilizing, and trading fibre flax (Vigo 2010). This is well-documented through the discovery of textiles, such as the use of flax bandages to wrap mummies (Heer 1872; Herzog 1929). Flax has been used for textile production since at least the Neolithic period. The oldest evidence of flax textiles in Ancient Egypt comes from the Fayyum site A and dates back to 5000 BC (Jones and Oldfield 2006). Other early textile findings belong to the Badarian period (4400–3800 BC), when linen textiles were used in burials, as well as for mats and skin clothing (Brunton and Caton-Thompson 1928, 19). From the Predynastic period (3800–3100 BC) onwards, linen textiles were commonly found in burials, often used to cover the body and also offered as grave gifts (Jones 2008). During the early Pharaonic period (3100–2100 BC), there was a highly developed technical production of high-quality textiles and fine yarns, including the production of "ultra-fine yarn" (Cooke and Gamal 1990).

Other evidence supports the extensive use of flax for fibre purposes. Wall paintings in the tombs of Sennedjem (TT1) and Ipuy (TT217) in Deir-el Medina in Thebes, dating back to the beginning of the 19th dynasty (thirteenth century BC), depict tall-growing flax that appears to have been harvested while still green. This suggests that flax cultivated for fibre use is being portrayed. On the other hand, proving the use of flax for oil production is considerably more challenging.

Unfortunately, detailed documentation of archaeo-botanical remains is rarely available for excavations on Egyptian sites. However, a recent study by Karg et al. (2018) has presented findings on a selection of Ancient Egyptian flax seeds. In this study, they compared seeds of the wild progenitor of cultivated flax, pale flax (*Linum bienne* Mill.), with seeds of cultivated flax. The dry climate of Egypt has played a crucial role in preserving not only the flax seeds but also the capsules. This preservation allows for the expansion of the application of a multidisciplinary methodology to analyse ancient plant material and gain insights into the evolution of flax in Ancient Egypt.

Material and methods

Desiccated preserved flax remains from Egyptian sites dating from the 3rd millennium BC to the second century AD (Fig. 1 and Table 1) that were collected at the end of the nineteenth century by Georg Schweinfurth, a German pioneer of archaeobotany and textile archaeology (Finneiser et al 2010; Fig. 2) were used for this study.

The flax capsules were measured with an Olympus SZX16 DP72 stereo microscope and by using an image analysis program. In Table 1 the identification code (ID), the dating of the Egyptian desiccated capsules, the number of measured capsules and the means of the measurements are listed.

In Appendix 1 all the samples are listed and, when possible, recontextualized.

Genebanks as reservoirs of the genetic diversity of cultivated plants offer excellent opportunities to assess the archaeological findings of remains of cultivated plants for identification. The great genebank pioneer and crop plant researcher N.I. Vavilov pointed already out that crop plants are documents of greatest relevance for historical research, similar to archaeological artefacts (Vavilov 1926).

Fig. 1 Map with the Egyptian sites described in the text

The flax collection at the Canadian National genebank (PGRC) is a world collection and covers the entire range of diversity in the species and includes many ancient landraces. The characterization data was generated during field trials planted from 1998 to 2008 at Saskatoon (Diederichsen et al. 2013). Based on comprehensive characterization, the classification into fibre flax, oil flax and intermediate flax according to Kulpa and Danert (1962) was conducted for all accessions (Diederichsen 2009). Measurements of recently grown flax of 2926 genebank accessions maintained by PGRC were considered. The raw data from the publication Diederichsen (2009) was used and we present here an analysis focusing on the capsule measurements. For measuring the width of the mature capsules, the measurements were done by passing the mature capsules through holes of defined diameter in a metal plate to determine in which of nine classes ranging from 5.6 to 9.1 mm the capsules fall. Ten capsules were assessed for each accession and the modal value was recorded. Capsule width was assessed for 2926 accessions.

It is possible to distinguish modern flax capsules from the different usage groups for oil and for fibre, as they differ in size (Diederichsen and Richards 2003).

The degree of the spontaneous opening of the mature capsules (dehiscence) allow to categorize the accessions into various groups. Data on dehiscence was collected from 2931 accessions. A rating scale was applied on ten capsules and the modal value was recorded.

The data collected on completely dehiscent flax accessions was eliminated from the PGRC collection because completely dehiscent capsules were not found in the ancient material.

Results

Table 2 shows that modern fibre flax accessions have a higher proportion of capsules rated as notably to slightly dehiscent compared to indehiscent. In typical oil flax, the capsules tend to be only very slightly dehiscent. Intermediate flax mostly has slightly dehiscent capsules.

Table 1 Egyptian sites with flax capsule findings. Characterization and measurements of the capsules

Dating	Site name	Sample ID	Number of capsules	Diameter in mm		Length	Breadth	Degree of spontaneous opening in mature capsules		
								Description capsule closure		Variety
3rd mill. BC	Abusir el-Meleq	SSchw169	n = 4	Average	6.07	6.80	6.09	B, C	More slightely dehiscent	Fibre
				Max.	6.25	7.00	6.22			
				Min.	5.91	6.68	5.93			
				Standard deviation	0.18	0.18	0.15			
3rd mill. BC	Abusir	SSchw388		Capsule fragments not measureable						
2nd mill. BC	Dra Abu el-Naga	SSchw165	n = 27	Average	Not measurable	7.72	6.31	F, G	Indehiscent	Oil
				Max.	Not measurable	8.45	7.06			
				Min.	Not measurable	6.37	4.88			
				Standard deviation	Not measurable	0.46	0.58			
2nd mill. BC	Thebes	SSchw171	n = 5	Average	Not measurable	6.80	6.44	F, G	Indehiscent	Oil
				Max.	Not measurable	7.67	7.03			
				Min.	Not measurable	6.05	5.44			
				Standard deviation	Not measurable	0.71	0.71			
2nd mill. BC	Sheik Abd el-Qurna	SSchw170	n = 2	1 capsule, 1 fragment Not measureable				G	Indehiscent	Oil
2nd mill. BC	Sheikh Abd el-Qurna	SSchw166	n = 10	Average	6.40	7.21	6.76	C, D	Slightly Indehiscent	Fibre/Oil
				Max.	6.97	7.73	7.39	E, F		
				Min.	5.94	6.43	6.14			
				Standard deviation	0.35	0.38	0.37			
			n = 10	Average	6.30	6.55	6.22			
				Max.	6.99	7.25	7.07			
				Min.	5.45	5.54	5.09			
				Standard deviation	0.51	0.48	0.64			
2nd-1st mill. BC	Assasif	SSchw164	n = 10	Average	6.53	7.02	6.69	C, D	Slightly Indehiscent	Fibre/oil
				Max.	7.37	7.63	7.15			
				Min.	5.76	6.09	6.07			
				Standard deviation	0.51	0.52	0.44			

Table 1 (continued)

Dating	Site name	Sample ID	Number of capsules	Diameter in mm		Length	Breadth	Degree of spontaneous opening in mature capsules	
								Description capsule closure	Variety
second century AD	Abusir el-Meleq	SSchw167	n = 10	Average	Not measurable	6.91	5.98	F, G Indehiscent	Oil
				Max.	Not measurable	7.48	6.50		
				Min.	Not measurable	6.53	5.29		
				Standard deviation	Not measurable	0.34	0.33		
			n = 10	Average	Not measurable	7.43	6.34		
				Max.	Not measurable	7.80	6.88		
				Min.	Not measurable	6.75	5.62		
				Standard deviation	Not measurable	0.37	0.38		

Fig. 2 Nicely decorated show box with flax capsules from collection Schweinfurth (SSchw166) with label handwritten by Schweinfurth. *Linum usitatissimum L. gefunden zu Schech Abd el Qurneh, Theben, in einem Grabe der XX Dynastie, das als Speicher diente dessen Inhalt in Vergessenheit gerieth. Man fand daselbst 1885 Ardeb Maspero. Linum usitatissimum* L. found in a grave at Schech Abd-el-Querneh, Theben, in a grave of the XX dynasty that was used as a granary but its content fall into oblivion. Found in 1885 by Ardeb Maspero

Table 3 displays the width measurements of flax capsules from the accessions at PGRC. A clear distinction is observed, as fibre flax has narrower capsules compared to oil flax. However, intermediate types also generally have narrower capsules. Figure 3 extracts the capsule width distributions for fibre flax and oil flax from Table 3, allowing for a better comparison of the two extreme groups.

Table 1 lists the measurements of ancient flax capsules from Egypt. A total of 88 capsules from the Schweinfurth collection were measured and categorized following the capsule dehiscence scheme in Diederichsen and Richard (2003). Of these, only 4 were categorized as "more slightly dehiscent". These are the oldest capsules, dating back to the 3rd millennium BC, found at the site of Abusir el-Meleq in Northern Egypt (SSchw169; Figs. 4a, b). The four capsules are more slightly dehiscent (a bit open), rather small in size, and interpreted as belonging to a fibre flax variety. The capsules clearly show 10 segments, indicating that each capsule originally contained up to 10 seeds. Flax capsules from the 3rd

Table 2 Dehiscence of mature capsule in genebank material

Varieties of *Linum uistatissimum*	Group	Number of entries	Capsule dehiscence ratings (number of accessions)			
			3 (notable dehiscent)	5 (slightly dehiscent)	7 (very slightly dehiscent)	9 (indehiscent)
Elongatum	Fibre flax	395	**176**	**191**	25	3
Mediterraneum	Oil flax	172	2	32	**119**	19
Usitatissimum	Intermediate	2364	363	**1131**	**786**	84
Total		2931	541	1354	930	106

The most frequent classes are bold for each flax type

millennium BC were also found at the site of Abusir (SSchw388), but they were fragmented and could not be measured (Table 1).

Most capsules dating to the 2nd millennium BC appear indehiscent (closed) and larger in size compared to those from Abusir el-Meleq (SSchw169). They are therefore interpreted as belonging to an oil flax (linseed) type (SSchw165, SSchw171, SSchw170). The measurements of 20 capsules from the site of Sheikh Abd el-Qurna (SSchw166) do not clearly indicate a fibre flax type (Table 1 and Fig. 5a, b), and are thus characterized as an intermediate flax type (fibre/oil). The same observations apply to the capsules from the site of Assasif, dating to the 2nd-1st millennium BC (SSchw164): the capsules are quite large and slightly open, indicating an intermediate flax type used for both fibre and oil production. The more recent flax capsules from the site of Abusir el-Meleq (SSchw167), dating to the second century AD, are large and closed, clearly indicating a seed/oil usage type of flax plant.

Discussion and conclusions

For the first time, desiccated flax capsules from ancient Egyptian sites were studied and compared with measurements and morphological features of modern genebank material. The comparisons show that the oldest flax finds, dated to the 3rd millennium BC, were probably fibre flax types. In all later periods, an intermediate flax and/or oil type was in use, as supported by a previous study on Egyptian flax seeds (Karg et al. 2018). This result is intriguing and clearly indicates that fibre flax was already being used in the early Pharaonic history.

Most of the later flax findings originated from the Theban region and indicate its use for seed production. However, the Theban region may not have been the most suitable for cultivating fibre flax compared to the Delta, which had better access to water for achieving higher fibre yield and quality. The humid conditions in the delta environment have caused the destruction of ancient organic materials, including flax capsules, limiting archaeological findings to more arid areas.

Considering these challenges and the limited number of samples in this study, future investigations could explore the following questions: is there a distinct shift between the third millennium and the second millennium, with flax production leaning more towards the use of intermediate flax rather than the typical fibre flax used in the previous period? Alternatively, could there have been a regional differentiation, with fibre flax cultivation primarily occurring in wetland areas such as the delta, while the more arid southern area like Thebes focused on the cultivation of linseed flax? Did climate change during the second millennium BC create better conditions for the cultivation of an oil flax type? Was linseed oil in higher demand for food or for the embalming process of the dead, leading to more frequent use of this flax type as a grave gift? If a distinct type of flax for fibres was already available in the 3rd millennium BC, when did the selection and differentiation process start (or arrive) in Ancient Egypt?

Through this multidisciplinary study, we aim to demonstrate the possibility of uncovering answers to the question of whether ancient cultures intentionally selected and cultivated specific crop types for particular purposes. We suggest that the characterization data of genebank accessions should be utilized more

Table 3 Capsule width of modern flax accessions

Varieties of Linum uistatissimum	Group	Number of entries	Number of accessions in classes with caspule diameter (mm)									
			5.6–6.0	6.0–6.4	6.4–6.7	6.7–7.1	7.1–7.5	7.5–7.9	7.9–8.3	8.3–8.7	8.7–9.1	Mean
Elongatum	Fibre flax	394	2	45	**199**	**120**	22	5	1			6.72
Mediterraneum	Oil flax	172			7	23	**60**	**43**	30	7	2	7.53
Usitatissimum	Intermediate	2360	23	234	**862**	**900**	258	60	22		1	6.80
Total		2926	25	279	1068	1043	340	108	53	7	3	6.84

The most frequent classes are bold for each flax type

frequently to shed light on the ancient history and evolution of cultivated plants.

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Declarations

Conflict of interest The authors have not disclosed any competing interests.

Appendix

The original labelling of the boxes from which flax seeds and/or flax capsules were studied were translated into English by the first author of this article. In addition, the total number of seeds and capsules that could have been measured is given. We also mention if the finds were photographed. The sites are listed according to their age by starting with the oldest sample. If available, more information on excavation and context of findings are also provided. The following listing is justified in order to simplify the retrieval of the single finds and excavations in case of future investigations to be carried out by other researchers.

Abusir el-Meleq, SSchw169 dated to 2925–2700 BC

Original box: *„Linum us.v.crepitum L. Abusir Melaq. Protohist. Gräber. (…II^{n} Dyn.) 1906 Dr. G. Möller “.*

Linum us.v.crepitum L. Abusir Melaq. Protohistoric graves (…2nd dynasty) 1906 Dr. G. Möller.

Content: Four flax capsules and four seeds. All measured and photographed.

Context of finding: Abusir el-Meleq, excavations of Georg Möller of the Proto-dynastic cemetery in 1905–1906. Flax capsules are only reported in tomb

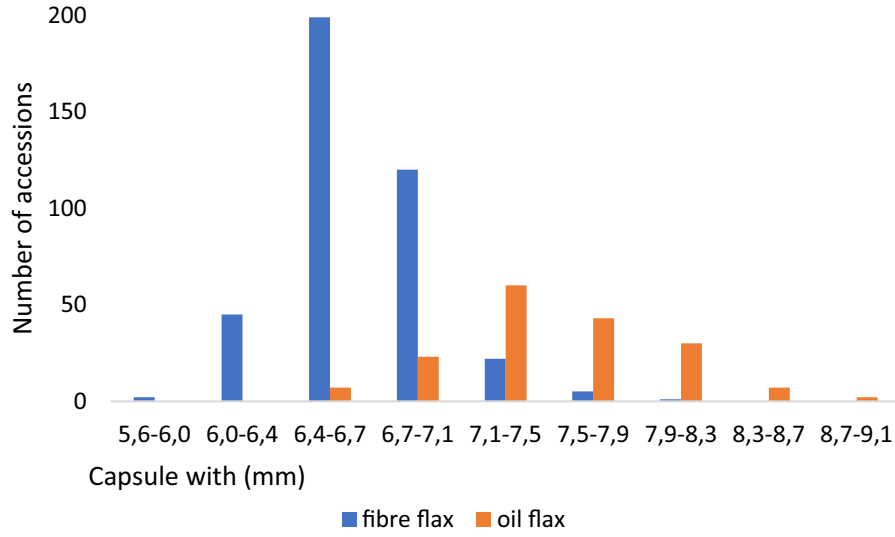

Fig. 3 Capsule width distribution in modern gene-bank accessions of fibre flax (n = 394) and oil flax (n = 172)

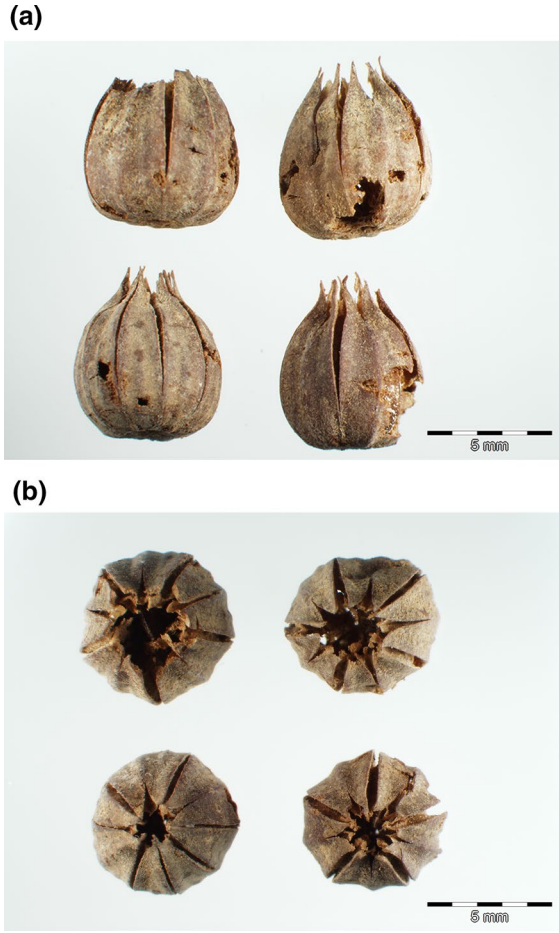

Fig. 4 **a**, **b** Egyptian flax capsules from the Schweinfurth collection (SSchw169)

12, positioned in front of the face of the deceased (Scharff and Möller 1926, 115).

Abusir, SSchw388 dated to 2510–2460 BC

Label on original box: *„Nr. 17 Linum us. L., Fundamentopfer des Sahu-re V. Dynastie. 1910 “.*

Number 17 Linum us. L., basement offering of Sahu-re, 5th dynasty. 1910.

Label placed in box: Borchardt 1909.

Content: Flax capsules and capsule fragments, no flax seeds, two additional seeds, one is probably *Coriandrum*.

General photograph, flax capsule cross section and capsule basis photographed, in each case the outer- and the inner part.

Context of finding: Pyramid complex of Sahura in Abusir, excavated by Ludwig Borchardt between 1902 and 1908.

Dra Abu el-Naga, SSchw165 dated to 1994–1781 BC

Original box: *„38 Linum us. L., eine Schale mit diesen Capseln gefüllt fand sich wiedergelegt in einem Grabe der XII. Dynastie für Dra Abu`l Negga, Theben. Gefunden von Mariette.”*

38 Linum us. L. the capsules were placed in a bowl in a grave dated to the 12th dynasty for Dra Abu`l Negga, Theben. Discovered by Mariette.

Fig. 5 **a**, **b** Egyptian flax capsules from the Schweinfurth collection (SSchw166)

Content: 28 flax capsules were measured and photographed through the glass lid of the sealed box.

Context of finding: Auguste Mariette conducted several excavations in Dra Abu el-Naga (Western Thebes, modern Luxor) between 1957 and 1962 but has never published a full report (Miniaci and Quirke 2008).

Thebes, SSchw171 dated to 1552–1295 BC

Original box: *„Fruchtkapseln von Linum us. L. aus einem Speicher von Priesterwohnungen, Theben 1911, XVIII^{e} Dyn. Gefunden von Dr. G. Möller."*

Capsules of Linum us. L. from a store in the home of a priest, Theben 1911, 18th dynasty. Discovered by Dr. G. Möller.

Content: Three entire flax capsules and five capsule fragments. All are measured and photographed.

Context of finding: Georg Möller was active in 1911 in the area of Sheikh Abd el-Qurna (Western Thebes, modern Luxor). His works are currently under study by the Ägyptisches Museum und Papyrussammlung in the project "Ausgrabungen auf dem Westufer von Theben (1911; 1913)".

Sheikh Abd el-Qurna, SSchw170 dated to 1188–1069 BC

Label on original box: *„Linum usitatissimum. Gefunden zu Schech Abd el Qurneh Theben in einem Grabe der XX Dynastie, der als Speicher diente dessen Inhalt in Vergessenheit gerieth man fand daselbst. 1885. 8 Ardeb (?) Leincapseln "*.

Linum usitatissimum found at Schech Abd-el-Querneh in Theben in a grave of the 20th dynasty. The grave was used as a granary in antiquity but later forgotten. 1885. 8 Ardeb (?) flax capsules.

Content: One entire flax capsule and one capsule fragment, both are photographed.

Context of finding: In a tomb of the 20th dynasty. Considering the similar description of number 166 (see below), it might belong to Gaston Maspero excavation as well.

Sheikh Abd el-Qurna, SSchw166 most probably dated to 1189–1069 BC

Original box: *„Nr. 19 Linum usitatissimum. Gefunden in einem Grabe zu Schech Abd-el-Qurneh, Theben, das im Alterthum bereits als Speicher diente und in Vergessenheit gerieth, man fand daselbst … Ardeb Leincapseln 1885 Gurna Maspeso "* (see label on Fig. 2).

Number 19, Linum usitatissimum found in a grave at Schech Abd-el-Querneh in Theben. The grave was used as a granary in antiquity but later forgotten… Ardeb flax capsules 1885 Gurna Maspero.

Content: approx. 500 uncharred flax capsules most of them entirely preserved, few breakages, approx. 120 seeds mostly still attached to the capsules. The sample contained furthermore ceramic fragments, uncharred bones, stones (mortar droppings?), a few uncharred cereal grains from barley, twisted pods from small seeded legumes, a few stems, 2 charred fragments of probably olive stones.

100 flax seeds (Karg et al 2018) and 20 capsules were measured and photographed.

Context of finding: Gaston Maspero was active in the area of Sheikh Abd el-Qurna (Western Thebes, modern Luxor) in 1886. His excavation reports have never been published.

Assasif, SSchw164 dated to 1188–525 BC

Plastic box: *„Lein Kapseln, Linum us. XX.-XXVI dynastie, 88 Mus. Bot. Berol."*

Flax capsules dated to the 20–26th dynasty, 88 Mus. Bot. Berol.

Content: approx. 60 uncharred capsules. 10 capsules were measured and photographed.

Original box: *„39 Linum us. L. in Gräbern beim Assasif zu Theben, XX-XXVI Dyn. 1885 gefunden von Prof. Schiaparelli."*

39 Linum us. L. in graves at Assasif in Theben, 20–26th dynasty 1885 discovered by Prof. Schiaparelli.

Content: approx. 70 flax capsules. 10 capsules were photographed (top and side view) through the glass lid of the sealed box.

Context of finding: Ernesto Schiaparelli was director of the Museo Archeologico Nazionale di Firenze from 1881 to 1893. His first two expeditions

to Egypt date into that period, one in 1884–1885 and one in 1891–1892, where he mainly acquired items from dealers. The label on the box points to some graves located in the Assasif (Western Thebes, modern Luxor).

Abusir el-Meleq, SSchw167 dated to the second century AD

Original box: „*Linum us. L. als Totenbeigabe in Gräbern des 2.[ten] Jahrh. nach Chr. bei Abusir-el-malak 1903. Ausgrabungen von Dr. Rubensohn*."

Flax as grave goods in burials dated to the second century AD at Abusir-el-malak 1903. Excavations by Dr. Rubensohn.

Content: 33 flax capsules (one half). 20 were measured and photographed.

Context of findings: Otto Rubensohn excavated a necropolis in Abusir el-Meleq during four archaeological campaigns between 1902 and 1905. He discovered graves from the pre-dynastic to the Islamic period in Egypt, with finds from the third intermediate period until the Greco-Roman epoch (Rubensohn and Knatz 1904).

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