SECTION 5.11.2 LINSEED OIL
SECTION 5.11.2.1 THE DARKENING POTENTIAL OF LINSEED OIL
SECTION 5.11.2.2 CAUSES OF DARKENING
SECTION 5.11.2.3 PREVENTION OF DARKENING

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5.11.2 LINSEED OIL
There are many different quality factors in linseed oil, based on where the flax is grown, the ripeness of the seeds when harvested, how the oil is pressed, and how the oil is refined. Authors know the oil from a given time and place, making discussions of the ‘generic’ behavior of linseed oil misleading, because there is no such thing. The fatty-acid profile of linseed oil gives it the potential to dry quickly, but also means that quality processing is paramount to minimize yellowing potential. Yet, because there are several other factors that can increase this potential, (see section 5.11.2.1 below), quality oil that has been perfectly cleaned may also yellow under certain conditions. The slow ripening of the seed in northern climates is often said to produce better oil, as is the ripest seed. However, fully ripe seed scatters so easily that it must be hand-harvested, creating a basic difference between older oil and any modern oil. Wehlte points out that it is natural to be drawn to the lightest oil, but that a lighter oil may dry darker due to the way it has, or has not, been processed. It is possible to make an oil colourless with bleaching clay, as is often done with commercial oil, but this has no effect on the yellowing potential of the oil. Cold-pressed linseed oil has less yellowing potential than hot-pressed or alkali-refined linseed oil. But it is also important that a cold-pressed oil be refined to remove the water-soluble mucilage and associated impurities: this type of oil is available in bulk through bulk natural oil sources, but is rarely sold in the art supply marketplace. Alkali-refined linseed oil can be purchased from many suppliers. This oil typically yellows minimally, but does not polymerize quickly, and has little working personality. This is because all commercial oil is refined by the same process used for edible oils. The goal of this process is to increase shelf-life. That is, to prevent oxidation, i.e., rancidity. This process removes not only the mucilage and phospho-lipids, but also the free fatty acids that, on older methods, provide a natural avenue to a quick-drying oil by attracting oxygen. This is why the commercial linseed oils do not to oxidize, or dry, readily, and lack the tight body generated by all the water-based older methods.

HAND-REFINED VS. COMMERCIAL OIL
A basic difference between older and modern practice is the behavior of the oils involved. This is especially the case with linseed oil. The cold-pressed, hand-refined linseed oil of older practice creates a variety of materials and effects that are difficult to achieve in a stable manner otherwise. As a family, the water-refined linseed oils perform very differently than the current
commercial alternatives. This is because, first, these oils dry quickly on their own, and, second, when autoxidized — thickened in response to air — these oils become quite thick or resinous compared to the leveling or flowing rheology of stand oil. While both types of oil are thick, and increase saturation, they are otherwise opposites. In most formulas, commercial oils can be substituted for handmade, water-refined oils, but, this results in longer drying times, and the loss of some, if not all, of the original rheology. This is not an issue for smooth surface work, but if the style seeks to capitalize of the basic personality if the paint, it may be.

Quality painting systems can be constructed around contemporary alkali-refined oils. But, in terms of the way older painting operated — especially when dealing with broken surface styles — modern oils are inherently different than hand-refined oil because the more resinous or adhesive rheological potential of the oil has been eliminated by the commercial refining process. (The single exception is triple boiled oil, see section 6.2.4.2, a pure but relatively expensive industrial oil that has never been popularized, or marketed, for oil painting). Refining the oil involves extra effort, and, within a given practice, oil of this quality may or may not matter. But for exploring the creative potential of the older craft, or how and why this craft developed the ways it did, the possibilities of hand-refined linseed oil may prove interesting.

HAND-PRESSED OIL

Wehite mentions the primitive older oil extraction method and suggests that it produced higher quality oil. This has been confirmed by recent research (9.11.4). Due to its role in human nutrition, fresh organic brown flaxseed is now readily available. Hand-pressing linseed oil using a primitive lever press or a small hand-cranked press offers another level of quality in the unrefined oil. This is because the oil is pressed at a relatively low temperature compared to the 100°C allowed for commercial cold-pressed oil, and because the oil is only pressed once, not twice, as is the commercial standard to increase yield. Research has shown that single pressed oil has a significantly higher iodine number, and a significantly lower saponification number, than double pressed oil, meaning that the fatty acids are more intact. Single press oil also has significantly less phenols, meaning it will oxidize faster (9.11.4). Limited experience with low-yield, single-pressed hand-refined oil has shown that it does dry faster, and has less tendency to yellow when newly processed, than even the highest quality — low pressing temperature — nutritional oil commercially pressed from gold seeds. These differences are not huge, but are noticeable.

5.11.2.1 THE DARKENING POTENTIAL OF LINSEED OIL

A variety of factors affect the potential of linseed oil to yellow. In chronological order, these are:

- The climate in which the flax is grown: cooler better than warmer
- The ripeness of the seeds when harvested: the riper, the better
- The pressing temperature: the lower, the better

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1 Such as the one manufactured by Piteba
• The number of presses: *two is usual, one is optimal*
• The refining method: *milder rather than stronger ingredients*
• The amount of relative humidity as the oil polymerizes: *less is better*
• The amount of light the oil receives as it polymerizes: *more is better*
• The thickness of the paint layers: *thin layers are helpful*
• The resistance of the dried film to humidity: *sequestering is helpful*
• The light level in which the work exists over time: *more is better*

Lower quality commercial linseed oil – hot pressed, acid washed – is now rare in artists' paint. This type of oil is often a cause of darkening in 20th century paintings, although these are often altered for reproduction to look as they did when they left the easel. If linseed oil is used with a higher chroma palette, it needs to be cold-pressed, and refined. If even cold-pressed oil is not refined, the paint film will contain the non-polymerizing impurities, making it weaker, and giving it more potential to darken over time through the ongoing polymerization of the triglycerides in the presence of the impurities and their ongoing attraction of atmospheric humidity.

The initial yellowing of linseed oil occurs through byproducts of the polymerization process. Conjugated unsaturated hydroperoxides are converted into conjugated unsaturated ketones, which can then produce long-chain polyenes with a yellow colour. If the hydro-peroxides are reduced, or eliminated, this process can be curtailed before it begins. ‘Semi heat-bodied oil’ is often found in older paintings in the NG research. A recent study (9.11.10) shows the way in which a specific amount of heat (from 25°C to 120°C) applied to linseed oil first generates, then eliminates, hydroperoxide content in the oil. The amount of hydroperoxides generated, and the amount of time to both create and eliminate them, decreases with greater amounts of heat. According to the study, (done with a commercially refined linseed oil from Pebeo), at 25°C hydroperoxides peak at 600 hours, then have declined markedly by 1200 hours. This amounts to the effect of three months storage at slightly above room temperature, and might be approximated by a temperate zone summer on a south facing windowsill. At 120°C hydroperoxides peak at one hour, and are eliminated at ten hours. Extrapolation suggests that at 150°C hydroperoxides peak at half an hour, and are eliminated after four hours.

This helps explain the historical use of preheated oil. The primitive pressing of older oil at low temperatures may have contributed to its stability. Aging also eliminates the *orbitides*, a class of cyclic peptide that, though present in small amounts, can also contribute to yellowing.

High humidity is a proven cause of darkening. Museums control humidity levels rigorously. Unpigmented oil tests done in low humidity (winter) often darken in high humidity (summer), and then slowly become lighter again in low humidity. Painters working in high humidity countries – England, the Netherlands – faced a more challenging situation than painters working in Spain or Italy. Humidity can attack a recently dried painting, or a dried painting on stretched canvas from behind, unless the back of the canvas is sealed. High humidity accelerates the fading of less permanent pigments even in oil (NG25). The paint film is safeguarded most when it is protected
from moisture both front and back. Alla prima or final indirect layers benefit from small additions of prepolymerized oil. Prepolymerized oil forms a less permeable film than raw oil; faster drying paint also minimizes yellowing when driers are excluded. Thermal polymerization makes a stronger film than autoxidation, which tends to yellow less for the same quality and thickness of oil. The difference once the oils are in pigment is slight, and, as little thicker oil is used, handling differences are also a factor. See also Minimizing Yellowing in Autoxidized Linseed Oil, section 6.2.1.1.

The thickness of the oil, and the thickness of the paint film itself, are also a factor. Yellowing tests often show exponential darkening where the film is thicker, especially with autoxidized linseed oil, where non-polymerized oil is trapped beneath the polymerized surface. Thus, several thin layers yellow less than one thick one. Avoid the over-saturation of an alla prima or final layer; this can lead to lowering of tone over time. Alla prima painters often overstate the value and chroma of the finish in thick and saturated paint for these reasons.

Mild alkaline additions such as bone ash, chalk or other calcium carbonates contribute to slightly faster drying and a more buffered paint film over time. Tests show hand-refined linseed oil preheated with ground calcite or bone ash (Formula 31, section 6.2.2) to be uniformly resistant to yellowing. This may be because the calcium linolate produced by the process is not water soluble. Finally, to maintain fine colour and value shifts using a full chroma palette of modern pigments, sequestering agents such as egg yolk, beeswax, and small amounts of resin are helpful to further exclude oxygen and humidity, see section 6.1.7.

5.11.2.2 CAUSES OF DARKENING
In his remarks on Chardin in the Salon of 1767, Diderot comments that, while the work may appear too bright, Chardin knows it will darken or lose chroma over time (9.2.4.75). This points out that a probable aspect of the medium is a lowering of tone as the paint film ages due to the refractive index of the oil increasing, the action of oxygen and humidity on the medium ingredients, and the darkening of the ground itself. As such, when made with permanent pigments, oil paintings do not get lighter or brighter over time. Darkening can be caused by several different factors.

Oxidized Solvent: Yellowing potential increases when solvent oxidizes by exposure to light and air in a partially full container of clear glass. This is especially the case for high VOC solvents like turpentine, the oxidized residue of which yellows badly and affect everything it is part of. A large part of the long-term yellowing of soft resin varnishes is due to oxidized turpentine. If turpentine is necessary, use the highest quality, tested for complete evaporation, and protected from both light and air. Store any organic solvent in amber glass, refill with pebbles to exclude oxygen (a procedure from Wehle). See Solvents, section 5.13.

Painting on a Dark Ground: Even when followed by the dense use of white to reiterate the higher values – as can often be seen in x-rays of older paintings on a dark ground – a toned ground or darker underpainting may have the long-term effect of lowering the midtones. Currently, the strength
of titanium white is often used to hide yellowing of the oil, to paint light over dark, even as an eraser for unsuccessful passages, but the ultimate brittleness of titanium films may make this approach less than ideal over time on canvas. Using a white or light ground remains a good idea, as does keeping the value scale high in early layers.

Oils that Darken: The oil used by larger manufacturers has always been refined industrially, making lower quality hot-pressed linseed oil often a cause of darkening in 20th century paintings especially. Paint from small 20th century concerns, such as Laurie’s Cambridge Colours, David Davis in Manhattan, and Lefevre-Foinet in Paris, may have used higher quality oil. The oil in general use at this point is higher quality, but there is still no major manufacturer using refined, cold-pressed linseed oil to make their paint. With respect to linseed oil especially, it is important to be aware that there can be differences from one oil to the next, and do tests with an oil or paint that becomes problematic.

Pigments that Darken: Manganese compounds used as driers have been shown to darken over time in oil, and the manganese-based pigments are not an exception. These include manganese violet, manganese blue, raw umber, and burnt umber. The latter two, especially, have been used in an underpainting for their quick-drying qualities, only to have the painting itself darken with an umber cast over time as a result. Given that these colours can be made from other earth pigments, and that all earth colours dry quickly, it is safest to avoid the umbers in oil.

Use of Driers: The overuse of concentrated modern metallic driers is a common cause of darkening. Driers tend to creep into official acceptance because no commercially refined oil (or alkyd) dries well without them. This in turn may compromise the long-term strength of the paint film. Dali, again in agreement with Jacques Bloch, warns against the use of any modern drier. On the other hand, Eastlake, Merrifield, NG and RAM all consider the use of lead in older oils as given, substantiated by De Mayerne and many other older texts. Moderate use of traditional lead salts at room temperature can be practically non-yellowing, but leaded oil is safest in the white light-brown shadow convention, with which it was originally used. Litharge (lead oxide) creates a gelatinous saponified oil with a characteristic swoosh that is often seen in older painting. However, lead is toxic, and if water-refined linseed oil is the basis of the system, unnecessary. A safe way to enhance drying moderately is with calcite, see Formula 31.

Overuse of Resins: Too much resin in a medium is often a cause of long-term yellowing or darkening. This is typically the result of overconfidence: because yellowing of resins is relatively slow, a little can easily become a little more. While solvent hygiene is important, especially high VOC organic solvents, the resin itself slowly autoxidizes and darkens in the presence of oxygen. For the sake of a solvent-free studio and the most homogeneous paint film, damar can be fused into the oil at a relatively low temperature, or a balsam can be mixed into the medium in small amounts. The darkening

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2 It may be possible to minimize yellowing of the resin to some extent by washing it to remove its water-soluble components, a procedure that appears to be historical in parts of northern Europe. See A Small Amount of Pine Resin, section 6.7.4.1
of oil varnishes such as copal or amber is longer term, and appears to be due to the temperature to which the oil must be heated to incorporate the resin; the resins themselves have already oxidized for centuries, even millennia. As such, the lower the temperature needed to make the varnish, the less it ultimately darkens if it is not thinned with solvent. The behavior over time of copal varnish in the paintings of the Pre-Raphaelites (PRPT) suggests that it can be used safely in small amounts. Experience with amber varnish suggests that it needs to be used with the expectation of some deepening of the values, unless offset by a strong brightener such as egg yolk (on panels). This makes amber more appropriate for the lower chroma or chiaroscuro centered work often seen in the 17th century than work featuring contrasting bright midtones: amber would not be logical for Perugino’s signature colour scheme of cold crimson, blue and green. It is best to use hard resin in minimal amounts, and never as a final varnish; technical art history shows this to be problematic both in terms of darkening and difficulty of removal.

**Final Varnish:** The anticipation of darkening is a topic that comes up in relation to varnishing. Was the painting made on the cold side, with the knowledge that aging varnish would make it warmer? The chilly look of certain Impressionist paintings once cleaned suggests this may have been the case, as it was with Italian 15th century egg tempera paintings designed for a final coat of vernice liquida, the red-orange oil varnish of the period, probably made with sandarac. Conservators generally recommend the addition of an ultra-violet absorber such as Tinuvin to help minimize yellowing in both the varnish and any varnish in the paint underneath (9.7.42). This is an area where preferred components can change: up to date research from conservation sources is recommended. See Final Varnishing section 6.13, and its subsections.

**Low Light Levels:** Recent conservation research (9.7.35) has established that many older pigments are more durable under low light levels, and this is the way older work is now exhibited in museums. However, the level of light involved is below the threshold at which the long-term yellowing of oil and resin is bleached by the light (9.11.16). This creates a zugzwang situation in which preserving the paintings means allowing them to darken somewhat diminishing chromatic accuracy, but through another means.

### 5.11.2.3 Prevention of Darkening

Interpreted literally, all oil mediums yellow to some extent over time. Yet, there is a difference between a gentle mellowing and darkening that disfigures the work. Once yellowing of the chosen ingredients in a system has been minimized, the relevant questions become how much the yellowing affects the whole system, and how much the system can be adjusted to offset it.

**Test Panels:** Materials exist in a complex context, both physically and chemically. The more this context can be reproduced in tests, the more those tests can offer reliable predictions. As a series of tests on a panel ages, it often generates a clear message about which directions to take, and which directions to abandon.
Tempera: If the goal is a medium that has the best chance of remaining bright and unchanged for centuries, tempera on panel remains the logical choice. Tempera is also reliable for lean and stable underpainting on panels. Oil-enriched tempera, often called tempera grassa, offers a middle point technically, see section 6.9.1.1. However, oil paintings made with technical forethought can remain bright, and be permanent, even on stretched canvas.

The Oil: Oil can yellow in a test and still not affect the whiteness of lead white, let alone titanium white. Technical art history, and the NG research, offer an overview of what actually happens over time, often to paintings that are on public view. Using linseed oil, the brighter the colour scheme, the more care must be taken that it is high quality, well-refined, and tested. Recent yellowing research done with commercial oil recommended an ‘extremely purified oil’ to avoid yellowing (9.11.16), a conclusion with which De Mayerne, Merrifield, and Eastlake agree. Another successful option suggested by Dr. Roland Greimers is to rebalance the fatty acid profile of linseed oil with a different oil. For example, ten percent poppy oil lowers the proportion of linolenic (C18:3) acid by 10 percent, and raises the proportion of linoleic (C18:2) acid by 25 percent. This brings the ratio of linolenic acid to linoleic acid from almost 4 to 1 in 100 percent linseed oil, to a little over 2 to 1. A 1 to 1 mixture of walnut oil and linseed oil lowers the proportion of linolenic (C18:3) acid by 40 percent, and raises the proportion of linoleic (C18:2) acid by 50 percent. This mixture brings the ratio of linolenic acid to linoleic acid to a little less than 1 to 1. This approach has proven especially effective to prevent yellowing in thicker autoxidized linseed oil. See Minimizing Yellowing in Autoxidized Linseed Oil, section 6.2.1.1.

The Colour Scheme: The focal issue is awareness of the materials and how they interact. If the colour scheme depends on cool, neutral light, or pure or cool midtone colour, yellowing needs to truly be minimal. Raphael’s higher chroma palette – often juxtaposing cool areas of ultramarine and red lake – capitalized on both walnut oil and quite thin layers of paint: the early Raphael panels are in remarkably good condition (NG25). At the same time, linseed oil was used by Rembrandt and Velázquez for low chroma charoscura, and by both Van Eyck, Vermeer, and many subsequent painters for work with a reasonable dependence on the higher chroma colours remaining unchanged. However, the recent cleaning of The Ghent Altarpiece suggests that, if the work was painted to the maximum chroma typical for religious subjects in the period, these colours have not remained fully bright, probably due in part to the increasing influence of a dark underpainting on thin layers of unsequestered overpaint. Similarly, works such as Vermeer’s Young Woman with a Water Pitcher (c.1660–62) are routinely brightened, albeit gently, for reproduction, possibly as a result of being shown in low light levels for long periods of time. Notably, the approach of Rembrandt and Velázquez exchanges brighter colour for intense psychological accuracy. This approach also takes advantage of the way the brown shadow–white light convention makes every cool colour appear far cooler in relation to the overarching warmth of the shadow structure.
Light and Time: Setting paintings to dry in moderate sunlight is a
traditional preventative for short-term darkening; a procedure recommended
in print for centuries, and confirmed by recent research (9.11.16). Paintings
darken if not exposed to enough sunlight, this is especially true of work
made with linseed oil. However, subsequent exposure to light brightens
the work again. This is the substance of the often-cited Rubens letter about
the painting rolled for shipment: once it arrives, exposure to light again will
restore its brightness.

Undercured Paint: When painting in layers, it is important to allow the
underpaint to dry thoroughly before overpainting. It is best if the underpaint
is either wet, or firmly dry. Going over soft paint can lead to darkening.
Underpaint can be quite thin and still be effective, it can also be in tempera
or a water-based medium. Scraping a wet layer in oil back offers creative as
well as technical potential. See Underpainting: Theory and Practice, section
7.9.1.

The Sequestering Agents: Using the traditional sequestering agents of egg
yolk, resin, and beeswax (see section 6.1.7) for alla prima work or later layers
of indirect work, as well as painting to the maximum level of acceptable
brilliance, combine to help colour stay brighter over time.

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